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OF
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ADAPTED FOR UPPER CLASSES IN
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BY

**BENTHAM SIMPSON,**
SCIENCE TEACHER, LONDON.
Author of "The Climate of the British Islands," etc.

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# INTRODUCTION.

In the present state of public feeling with regard to the importance of education, few, if any, will deny that it is as necessary to supply the youthful mind with knowledge as the body with food; or that, if our youths are to grow up into men and women fitted to take their places as good citizens and members of society, the cultivation of their minds is equally important with the nutrition of their bodies. That, in fact, the natural thirst of the youthful mind for knowledge should be equally satisfied with that of its body for food. This thirst for knowledge is manifested by children in many ways, but chiefly perhaps in trying to take their toys in pieces to find out how they are made, and in asking questions about almost everything they see.

How natural for a child, standing by the banks of a river, to inquire where all the water comes from? To inquire why grass is green? what makes it grow? how is it that birds can fly? why fishes are not drowned in the sea? or where all the sand comes from they see on the shore? They will ask, also, where the rain or the snow comes from? what is thunder? what are clouds? or how is it that the grass is so wetwith the dew? Thousands of questions like these are asked by thoughtful children, and what parent would not wish to be able to give them satisfactory answers? But to answer these questions satisfactorily requires a knowledge of natural phenomena, and the causes producing them. If any one of whom the child asked, whilst standing by a river's banks, "Where does all the water come from?" were to take him to his home, however humble, and show him the vapour rising from the water boiling for tea, and ask him to put a cool plate or glass in the path of the vapour for a few moments, and then look at it and notice the drops of water condensed upon it, and make him understand that these drops were formed by the vapour. Then explain to him that a great part of the earth was covered with water from which vapour was *always* rising, and that, when it rose into the upper regions of the air, it was condensed into drops of water, just as the vapour had been by the cold plate, and that when thus condensed it fell in rain. That a great part of this rain run on the surface of the ground, forming little streams and brooks, which were gradually joined by others, till those united streams formed rivers, which, by the unceasing flow, which had led to his question, gave back to the ocean the waters *which had been raised from them in vapour by the heat of the sun*, just as the vapour had been raised from the water boiling for tea by the heat of the fire. What child would readily forget such a lesson? Or what child, constantly so replied to, could fail to grow up an intelligent observer of all the natural events occurring around him?

But the person who could thus intelligently answer such questions would be truly a *natural philosopher*, and the replies he gave to such questions would be *instruction in natural philosophy*. The following pages, though of no great pretension, are believed to contain as much information as would answer all the most important questions that would naturally be asked by any one wishing to be acquainted with the causes of the principal phenomena that are constantly taking place in the world around him. It is believed, also, by the writer, that if they be read by intelligent children, such as are found in the upper classes of our elementary and middle class schools, and familiarly explained to them by teachers who take an interest in the success of their pupils, and who will endeavour by simple illustrations to help them to thoroughly master each subject *as they proceed, that* the pupils who have thus studied the following pages will go out into the world with an amount of knowledge regarding the operations of nature which has not been previously afforded by any work of the same extent, or which could so readily be used as a text-book on the subject in the generality of schools.

Some may think that in an elementary work on physics it was unnecessary to enter so minutely into the properties of matter, and especially to draw such distinctions between the properties of, and forces acting upon, matter in the mass and those properties which belong only to molecules, and those forces which act only at insensible distances. But, though this might be unnecessary in older works on natural philosophy, it seems now, since the numerous facts brought to light by the discoveries of modern science, that any work professing to treat of the subject scientifically should make those distinctions clearly understood. The following extract, copied from Tyndall's work on "Faraday as a Discoverer," will show this more clearly than any words of the writer:—

"At the end of his papers, when he takes a last look along the line of research, and then turns his eyes to the future, utterances quite as much emotional as scientific escape from Faraday. 'I cannot,' he says, at the end of his first paper on magne-crystallic action, 'conclude this series of researches without remarking how rapidly the knowledge of molecular force grows upon us, and how strikingly every investigation tends to develop more and more their importance, and their extreme attraction as an object of study. A few years ago magnetism was to us an occult power, affecting only a few bodies; now it is found to influence all bodies, and to possess the most intimate relations with electricity, heat, chemical action, light, crystallization, and, through it, with the forces concerned in cohesion; and we may, in the present state of things, well feel urged to continue in our labours, encouraged by the hope of bringing it into a bond of union with gravity itself.'"

But though the great importance of a knowledge of molecular forces is thus more and more important to the student of natural philosophy, yet the extreme minuteness of these molecules themselves is perhaps nowhere more distinctly proved than by an experiment mentioned by Professor Tyndall, in his address to the British Association at Liverpool in 1870, in which he showed that, after the presence of these molecules had been manifested by their action on light and their production of the *ethereal blue*, they went on increasing in size for fifteen minutes, and still were too small to be detected by the most powerful microscope, though, had they been of even the $\frac{1}{1000000}$th of an inch in diameter, he was assured by Professor Huxley they could not have escaped detection. Well might he therefore say, "*What must have been the size of these particles at the beginning of their growth?* What notion can you form of the magnitude of such particles?" and afterwards to add, "We are dealing with infinitesimals, compared with which the test objects of the microscope are literally *immense*."

In using this as a text-book, I would advise all teachers to let their pupils see, if possible, actual illustrations of either the properties of matter or of the phenomena actually described. Take, for instance, the property of *impenetrability* as one of these essential to molecular matter, and yet rather difficult popularly to explain. First give them the general notion that impenetrability in a general sense applies to matter in masses by showing them that, with regard to themselves, desks, slates, books, &c., no two could occupy the same space at the same time. Then show them the experiment described in the first part of the paragraph treating of *porosity*, and they will then see how in the mass the stones, sand, and water were successively penetrated by the substances introduced after each other. Then explain to them that still the fluid could absorb, without apparent increase of volume, 400 to 500 times its bulk of sulphuretted hydrogen.

They would thus be gradually led to understand that, though, with regard to masses of matter, there were *numberless instances* of apparent penetration of one body by another, and an actual *separation* of the particles of one body by another, yet that the smallest particles or molecules of matter, *which could not be divided*, could not, for that very reason, be penetrated or separated by any other substance.

Take, as another example, the chapter on the atmosphere. It will be easy for any teacher actually to perform the different experiments mentioned in the presence of his class, and then to make them understand the motion of the air and the origin of winds, &c.; he may show them that, as heat expands all bodies, and thus makes them bulk for bulk *lighter*, in consequence of their greater lightness they rise just as a cork does in water or a balloon in air. He may then tell them that the first balloons were filled with *heated air*, which rose in consequence of its being lighter than the colder air around it. Let them then be shown how the fires in our ordinary grates heat the air over them, thus causing it to ascend up the chimney, and carry with it the particles of smoke, &c., by the force of the current thus caused, just as the current of a river carries along with it stones, mud, &c., heavier than the water itself; and that, just as the stones, mud, &c., are deposited and form deltas at the mouths of rivers where the force of the current ceases, so the particles of soot, &c., carried up the chimney fall down again as *blacks* and *smuts* in our streets when the force of the current that carried them up the chimney is exhausted. He may then tell them the story recorded by one of the old chroniclers, who states that the wrath of heaven was so great against the inhabitants of London at the time of the great fire in 1666, that the winds of heaven blew from all quarters to increase the force of the conflagration, and lead them to see that this was the natural result of the ascent of the air heated by the force of the fire itself, the surrounding and colder air thus coming to supply the place of that which had ascended. He will then naturally speak of the great heat of the sun in equatorial regions, and the consequent ascent of the heated air, which causes a movement of the colder air from both north and south to supply its place.

Then remind them of *inertia* as a property of matter, and show them how, on account of the greater rotatory motion of the earth at the equator, the air, coming from places where that rotatory motion was much less, and possessing this property of *inertia*, cannot at once accommodate itself to the increased velocity of the earth from west to east, and therefore, to those persons who are carried along with the earth, must appear to come from east to west, as well as from the north and south, and that it is in this way we have our north-east and south-east trade winds wherever this movement of the air is not interfered with by local causes.

I have given this example in detail as a specimen of how an intelligent teacher may impress the substance of the following pages upon his pupils, and also make interesting to them a branch of knowledge the importance of which is becoming more and more apparent as the intellectual wants of the rising generation are becoming better understood.

In bringing this introductory chapter to a close, I will only add that the following pages have been to me a subject of anxious thought, and that, however deficient they may be, or whatever their imperfections, they have been written with the earnest hope that they might, in some humble way, be useful in spreading a knowledge of common things at present often very imperfectly understood.

It would have been much easier to have written in a more popular style, but it would not have been possible to do this and also to afford so much accurate information in so small a space. It is hoped, too, that the few necessary diagrams introduced will, to a certain extent, supply the want of longer verbal explanations, and that the few questions given at the end of each chapter may suggest others to the teacher, and may also aid him in discovering whether the substance of the chapter has been really understood by the pupil. If the extra labour bestowed on the following pages in condensing into the form of a *reading book* information which might *easily have* been extended over a much larger volume be the means of spreading more generally a knowledge of nature, and of making a few take a deeper interest in the natural phenomena taking place around them, this alone will amply repay the writer for the labour he has had in condensing the information respecting them so as to bring the volume within the reach of all the advanced pupils in our elementary or middle class schools.

B. S.

LONDON, *December*, 1872.

# OUTLINES OF NATURAL PHILOSOPHY.

## DIVISION I.

## CHAPTER I.

### Different Forms of Matter: Solid, Liquid, Gaseous, and Imponderable.

PHYSICS, or Natural Philosophy, is the science of nature, and its province is to treat of all natural phenomena, and to explain, as far as possible, the causes producing them. It has to do, therefore, especially with all kinds of matter, and the changes to which it is subjected under the influence of physical agents. All matter is either simple or compound; and it is especially the province of Chemistry to treat of its composition, and of the laws by which changes in its composition are effected. There are at present known about sixty-five substances, which, because they cannot be reduced to any simpler forms, are called elements; and just as all words and sentences, however complicated, are made up of letters, so all the known substances in the world are made up of combinations of these sixty-five elements. In the same way, then, as sentences may be separated into words, and words into letters, so the most compound substances may be reduced into simpler-ones, and these simpler ones into elements. The smallest particles of matter which can exist independently are called **molecules**, and these are themselves composed generally of still smaller particles, called **atoms**, which are held together by a force which is commonly called chemical affinity; but, inasmuch as this force is greatest between atoms most unlike in their nature, it seems more suitable to call it **chemical attraction.** The forces which regulate the arrangement of the molecules of which matter consists are called molecular forces. These forces are of two kinds—one tending to bring the molecules closer together, and called molecular attraction; the other tending to separate them farther from each other, and called molecular repulsion. According to the relation existing between these two antagonistic forces, the molecules of bodies assume one or other of the following states or forms:—

*First.* The solid form, as seen in rocks, trees, metals, &c. In this state of matter the attractive force of the molecules is so much greater than their repulsion, that their relative position cannot be changed without the exercise of some force greater than that of gravity. It may be defined as that condition of bodies where the attraction of cohesion is greater than the attraction of gravitation, so that they will retain any form given to them, in opposition to the action of gravity. As the repulsive force is mainly, if not entirely, due to the action of heat, whilst the attractive force is decreased by its agency, so an increase of temperature, if it produce no change in the composition of a body, will frequently so alter its molecular arrangement as to change the solid into the liquid or gaseous form, as in the change of solid ice into liquid water, and, by a still greater amount of heat, converting this liquid into vapour, as in changing water into steam.

*Second.* The liquid state, as seen in water, oil, ale, spirits, &c. In this state the attractive and repulsive forces are so evenly balanced, that the molecules, whilst remaining together, yet move amongst each other with the greatest freedom. It may be defined as that condition of matter where the attraction of cohesion is less than the attraction of gravitation; so that all the masses of water on the earth, under the influence of gravity, are found occupying those portions of its surface nearest its centre, unless they are supported by solid bodies capable of resisting its action.

*Third.* The gaseous state, as in air, oxygen, hydrogen, &c. In this state, the repulsive force is greater than that of cohesion and gravity together, so that the molecules are not only free to move amongst each other, but have a tendency to separate and occupy a larger space. It may be defined as that condition of matter in which the molecules constantly tend to recede from each other, in opposition to the action of gravity.

*Fourth.* The imponderable or incoercible state, as it exists in a form unrecognizable by our senses, and utterly incapable of being weighed by the most delicate balances. In this condition it is supposed to pervade all space, and to be the physical agent, the movements of which give rise to all the phenomena of heat, light, magnetism, and electricity.

### QUESTIONS ON CHAPTER I.

1. What is natural philosophy, and of what does it chiefly treat?
2. Give examples of matter in the solid, liquid, gaseous, and incoercible forms.
3. What general effect has heat on bodies? Give examples of this action.

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## CHAPTER II.

**Properties of Matter: Impenetrability, Extension, Shape, Inertia Divisibility, Porosity, Elasticity, Hardness, Ductility, and Malleability.**

As Physics have to treat chiefly of matter, it seems necessary, before proceeding further, to mention and define its principal properties, which are as follow: —

*First.* Properties belonging, not to masses of matter, but only to the molecules and atoms of which masses of matter are composed.

*Second.* Properties common both to masses of matter and to the molecules composing them.

*Third.* Properties common to masses of matter only, and not to the molecules of which those masses are composed.

*Fourth.* Properties belonging peculiarly to bodies in the solid form.

*First.* **Impenetrability**, which is a property not belonging to masses or aggregations of matter, but peculiar to the atoms and molecules of which masses are composed. It is that property which prevents any two atoms or molecules from occupying the same space at the same time. When we come to speak of the porosity of masses of matter, we shall find that the molecules of one form of matter do penetrate into the pores of other forms, and thus two forms of matter may, as masses, occupy the same space at the same time; but with regard to the atoms and molecules, they must necessarily remain distinct.

*Second.* Properties common both to the masses of matter and the molecules of which they are composed.

*a.* Extension or magnitude is that property common to all matter, by which it occupies a certain portion of space. This extension, however large or small, must be in three directions—viz., length, breadth, and thickness. Extension in any one direction is reckoned by long measure, of which in England we take a yard as the unit, but on the Continent this unit is a metre. Extension in two directions is calculated by square measure, and is termed area; thus, a substance 8 feet long and 7 feet broad would have an area of 56 feet. Extension in three directions is calculated by cubic or solid measure; and just as we obtain the area by multiplying the length by the breadth, so we obtain the solidity or cubic measure by multiplying the length, breadth, and thickness together; so that a substance 8 feet long, 7 broad, and 4 thick would have a solid content of $8 \times 7 \times 4$, or 224 feet.

*b.* **Figure or Shape.**—It is evident that all matter existing must have some shape; and though it is impossible to know the actual shape of atoms or molecules, yet there are abundant reasons for believing them to be spherical. Though no matter can exist without having some shape, yet forms and figures may exist without matter, as in the case of shadows.

*c.* **Inertia** is a negative property of matter, by which it resists any change in its condition. If at rest, a certain force must be employed to put it in motion; and if in motion, force must be employed to reduce it to a state of rest. Thus, a stone falls to the ground, not because of itself it would have a tendency to fall more than to remain at rest, but because it is acted upon by the force of gravity, and that force is not arrested till it meets with the resistance of the solid earth. This seems at first contrary to experience; for we are so accustomed to see all motion kept up by a continuous force, or terminating in a state of rest, that we seem to think a state of rest is natural to matter. Thus, whatever may be the velocity of a railway train, if the power of the engine be withdrawn, the speed gradually lessens, and it comes to a state of rest; and whatever the initial velocity of a cannon or rifle ball, they each soon come to the same condition. This, too, is the case with every kind of machinery: if the motive power be withdrawn, sooner or later—in proportion to the resistance—motion ceases. In fact, to find out some means of perpetual motion was the object of many enthusiasts before the laws which regulate motion were well understood. The reason, however, why bodies in motion come to rest, is not from any tendency in themselves to either rest or motion, but because the medium in which they move, however rare, always offers some resistance, and this resistance retards and ultimately destroys the motion imparted to them.

*Third.* Properties common to aggregations of molecules, and not to the molecules themselves.

*a.* **Divisibility.**—It was frequently a subject of discussion whether matter was infinitely divisible. It seems, however, now generally acknowledged that a limit exists to this division, and that all matter is made up of exceedingly minute and indestructible particles, which, from their not admitting of further division, are called atoms. How exceedingly minute those atoms are may be judged from a few simple and well-known facts, which show to what extent matter is capable of division. Gold may be beaten into leaves so thin that it would take 360,000 of them to be an inch in thickness; and in wire-drawing, 2 ounces of gold may be made to cover a wire nearly 800 miles in length. One grain of iodide of potassium will give a blue colour to nearly 500,000 oz. of liquid. A small quantity of musk or a few rose leaves will scent a drawer in which they are placed for years; and a drop of almost any fragrant oil placed in a handkerchief will fill a room with its perfume.

*b.* **Porosity.**—If any vessel have placed in it as many large and irregularly-shaped stones as it will contain, a considerable quantity of smaller stones or sand can be made to enter the vessel, and partly fill up the cavities or spaces between the larger stones. If water be then poured into the vessel, it will be found that a considerable quantity will pass into it before it overflows; and when it is apparently full, if salt or sugar be gradually placed on the surface of the water, it will dissolve a large quantity before the water be increased in bulk and flow over the vessel. Now, the spaces between the large stones could be easily seen, and would be called cavities; the spaces between the particles of sand could be less easily seen, and would be termed interstices; whilst similar spaces, as they occur and can be seen in wood, sponge, the skin, &c., are called sensible pores. In the water those pores evidently existed, or the salt and sugar could not have been dissolved in it without increasing its volume, The pores which exist in all bodies, but which cannot be seen, are called insensible or physical pores. That gold, silver, and other metals possess physical pores, has been frequently proved by filling three globes of these metals with liquid, and then submitting them to pressure, when the liquid has passed through the metals of which the globes were made, and appeared outside in the form of dew. The amount of porosity is influenced chiefly by chemical action, temperature, and *pressure.* When different bodies combine chemically, they generally occupy less space than they did separately, and consequently their porosity, or the spaces between their molecules, must be decreased. An increase of temperature tends to increase the volume of bodies—consequently, to separate their molecules to a greater distance, and to increase their porosity. Pressure, on the contrary, decreases the volume of bodies, and consequently brings the molecules nearer together and decreases the porosity. A rough estimate of the volume of the sensible pores in any body may be obtained by immersing it in water, and determining its increase in weight. As a cubic foot of water weighs 1,000 oz., if the body without increase of volume weighed 1 oz. more after immersion, the volume of its sensible pores would be $\frac{1}{1000}$ of a cubic foot. There is therefore a difference between the real and apparent volume of a body. Its real volume is constant, and is the portion of space occupied by the matter of which it is composed; but its apparent volume is variable, depending on temperature, pressure, &c., and consists of its real volume and also the volume of its pores.

*c.* **Elasticity.**—If a piece of clay or mud be thrown against a wall, it will adhere to it; but if a marble be thrown against it, it will rebound with nearly as much force as it was thrown. If the ball be blackened, and thrown forcibly against a smooth surface, it will be found to have left a circular mark, and not a mere dot, showing that the ball on impinging against the surface had been flattened, so that a considerable portion of the circumference of the ball, and not a mere point, had come in contact with the surface. The force with which it tended to recover its natural shape, and caused its rebound, is called elasticity; and were it perfectly elastic, this rebound would equal the original force of impact. The fact of the clay and mud remaining on the wall, and having no tendency to recover their former shape, shows their want of elasticity. Elasticity in solids is nearly allied to flexibility; and though no solid body is perfectly elastic, and there are limits beyond which, if the body be compressed, it will either alter its shape or break, yet the elasticity of glass and steel within these limits is almost perfect; and copper, iron, caoutchouc, marble, &c., also possess it to a considerable extent. The resistance in perfectly elastic bodies is always proportionate to the compressing force; so that if a spring or bow be bent or compressed to the extent of 1 inch by a force of 20 lbs., it will be bent or compressed 1½ inch by a force of 30 lbs., 2 inches by a force of 40 lbs., &c.

Advantage is taken of this property in the manufacture of **spring balances**, springs for watches, timepieces, &c.; also in the manufacture of cushions, beds, and mattresses, whether the materials be of very elastic materials, such as wool, hair, feathers, air, water, &c., or whether they are mainly of less elastic materials, with steel springs inserted to increase the elastic force.

Liquids and gases are perfectly elastic to any extent; and whatever pressure be placed upon them, they will occupy their original volume on that pressure being removed.

Properties common to solids only:—

*a.* **Hardness** is that property of solids by which they resist being worn or scratched by contact with other bodies. It is only a relative term, and to judge of the hardness of any two bodies it is only necessary to determine which will make an impression upon the other. Diamond is the hardest substance known, and hence its use by glaziers for cutting glass.

Of ordinary rocks and stones granite is the hardest, and hence its use for paving streets and making roads where there is a great amount of traffic. It is on account of their hardness, too, that millstones, grindstones, and many kinds of building stones are selected; and it is this property chiefly that constitutes the difference between marble, limestone, and chalk. It is the want of hardness in gold, silver, and copper, that makes it necessary to alloy them with some other metal, so that they may be hard enough for coining, the manufacture of articles of jewellery, &c.

*b.* **Ductility.**—This is chiefly a property of the *metals*, and is that property which enables them to be drawn out into wire, rods, &c. Platinum is the most ductile metal; and by surrounding a wire of platinum with silver, so as to have a cylinder with its axis only of platinum, and then drawing it into a wire, one grain of platinum may be extended a length of more than 1,400 yards.

*c.* **Malleability** is similar to ductility, only it is the property of spreading out into thin layers under the action of a hammer, instead of being drawn out in lengths, as in wires. It is chiefly on account of their possessing the properties of malleability, ductility, and tenacity, that the most important metals owe their commercial value. Steel and wrought iron are, on account of their ductility and malleability, much superior to cast iron; as articles composed of the former can have any part of them renewed or repaired, whilst those made of the latter, when once broken, are rendered useless.

## QUESTIONS ON CHAPTER II.

1. Mention the different properties of matter.
2. How is extension measured in England?
3. When can form exist apart from matter?
4. What is *inertia?*
5. Is matter infinitely divisible? Give examples of minute division.
6. What may be put into a vessel of water when it is apparently full, without causing it to flow over?
7. How may you obtain an approximation to the volume of the sensible pores in any body?
8. What is the difference between mud and marble with regard to elasticity?
9. What use is made of elasticity in our common manufactures? Give examples.
10. Why is the diamond used by glaziers, and granite for making roads?
11. What is the difference between malleability and ductility?

## CHAPTER III.

**Definition of Force. Forces acting on Matter at Insensible Distances. Chemical Attraction, Cohesion, Adhesion, and Repulsion.**

**[Anything which produces change in the state of matter is called *force*, and this force is always proportionate to the amount of the change effected. Some forces act on matter only at insensible distances, whilst others exert their influence so as to pervade all space. This chapter will be devoted to those forces which act on matter only when its particles are *apparently* in contact.]**

**Chemical attraction** is that force which binds the atoms of a compound molecule together. It is by its agency that the most important changes are effected in the composition of bodies; and it always acts with the greatest intensity on bodies made up of atoms, the separate properties of which are most dissimilar. It is the chief agent in electrical decompositions, and bodies are divided into electro-positive and electro-negative, according as they are separated by it at the negative or positive pole. All the metals are classed with the positive—those most so being **potassium, sodium,** and **zinc**; whilst the most negative are **oxygen, chlorine,** and **sulphur.** Chemical attraction unites most firmly the negative and the positive bodies, whilst its force is very feeble in the case of molecules made up of two positive or of two negative atoms; and the slightest change of temperature is sufficient to separate them, whilst those of opposite kinds are separated with very great difficulty. Its force only acts at insensible distances, and substances generally require to be dissolved or converted into vapour before it can act upon them. It always unites atoms by weight in definite proportions, these proportions being known as their atomic weights; and it is assumed, for various reasons, that though these atoms differ in weight, they all, in the form of vapour, occupy the same volume. In the case of simple solid bodies, as iron, copper, carbon, &c., the atoms which compose their molecules are supposed to be held together simply by cohesion, chemical attraction only acting on those of compound bodies.

**Cohesion** is that property by which the separate molecules of all bodies and the atoms of simple ones are held together. It is this force which gives strength to materials, and which retains a block of wood, a rod of glass, or a bar of iron in one place. This force is generally estimated in one of two ways—either by finding the weight requisite to stretch a rod of given diameter till it break, or by finding out the amount of pressure necessary to crush a cube of given dimensions. It is the force used for welding, as in this process the iron is pressed or hammered together, at a white heat, till it coheres with the same force as if it had been originally of one piece. Smooth plates of glass will also, if placed on each other and pressed together, without any increase of temperature, sometimes cohere so forcibly as to be worked together as one plate. Two plates of clean zinc, copper, or any other metal, forcibly pressed together, will require considerable force to separate them. It was thought that this was caused by atmospheric pressure, and considered similar to the experiment with the Magdeburg hemispheres; but it is now known that if the experiment be performed in a vacuum, the force necessary to separate them is very little diminished. Cohesion, though so feeble in liquids as generally to be overcome by the action of gravity, yet exists to a sensible extent, as is seen in the rounded form of drops of rain, dew, &c.

**Adhesion** is the force with which bodies of an unlike kind adhere together, and may be exerted between one fluid and another, between solids of different kinds, or between a fluid and a solid. The force of adhesion between a liquid and a solid may be measured by placing a circular plate of copper at one end of a beam, and balancing it exactly by weights placed in the scale pan at the other, and then allowing the plate of copper to rest on a vessel containing water, when it is found that increased weights are necessary in the scale pan before they are able to raise the plate from the water. It has been found by this experiment that when the plate of copper was about seven inches in area, the weight necessary to overcome its adhesion to the fluid was nearly 1,000 grains.

**Repulsion** is that force which tends to separate the molecules of matter from each other, and which owes its energy to heat, being generally most energetic in proportion to the heat of the body. It is most active in gases, where it overcomes entirely the force of cohesion; less so in liquids, where the two forces are pretty evenly balanced; and least energetic in solids. Though mostly employed in separating molecules farther apart, and in overcoming cohesion, it also acts between the atoms of a molecule in opposition to chemical attraction, so that by the application of heat, the action of which is chiefly to increase repulsion, not only may molecules be separated farther from each other, but also the atoms of a molecule may be driven asunder and chemical decompositions effected.

### QUESTIONS ON CHAPTER III.

1. Mention the most positive and the most negative elements.
2. On what classes of bodies is chemical attraction the most powerfully exerted?
3. What is cohesion? and how is its force generally determined?
4. What is the difference between *cohesion* and *adhesion*?

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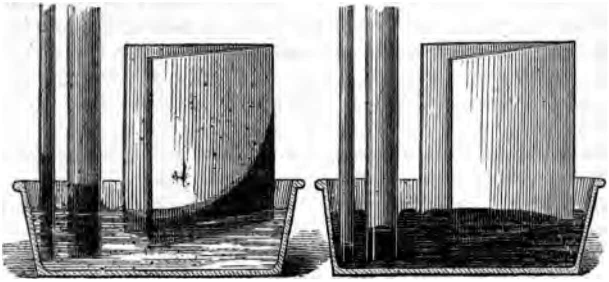
## CHAPTER IV.

Phenomena dependent on Molecular Forces: Capillary Attraction, Exosmosis and Endosmosis, Dialysis, Nutrition and Growth of Plants and Animals.

THE preceding forces, which act only at insensible distances, and which affect only the atoms or the molecules made up of these atoms, are called molecular forces; and they give rise to a certain class of phenomena, of which the following are the most important:—

*First.* **Capillary Attraction.**—This is so called because it is manifested in very fine hair-like tubes. If a number of tubes of different diameters be placed in a vessel containing water, it will be found that the water in the tubes rises higher than it does in the vessel, and that it rises highest in those tubes having the least diameters. If a clean glass tube be inserted in water, when it is withdrawn it will be found to be wetted by the water, and a certain quantity will adhere to the surface; but if the same tube be placed in mercury, on withdrawing it its surface will be quite free from the mercury. It will also be found that if a number of tubes of different diameters be placed in a vessel containing mercury, the mercury will be lowest in the tube of smallest diameter, and lower in the tubes than in the vessel; and consequently the phenomena are entirely opposite to those shown when the tubes were placed in the water. If, instead of tubes, plates of glass with two edges touching each other, and diverging at a small angle, be placed in the two fluids, the water will rise highest where the plates are nearest to each other, and gradually sink lower as the plates diverge farther, till it descend to the general level of its surface in the vessel; whilst, if they are similarly placed in mercury, its surface will be depressed where the edges of the plates are nearest, and gradually rise to the level of that in the vessel as they diverge. These phenomena arise from the action both of cohesion and adhesion. In the case of the tubes of glass and



ILLUSTRATIONS OF CAPILLARY ATTRACTION.

water, the adhesion of the fluid for the glass is greater than the cohesion of the particles of the fluid for each other; hence a thin film of water adheres to the surface of the tube, and then a thin column of fluid coheres to this; so that these two forces, acting to lessen the force of gravity, cause the fluid to rise in the tubes and between the plates; but, on the contrary, in the case of mercury and glass, they have less tendency to adhere than the particles of the fluid have to cohere together; and consequently the force of gravity will act more forcibly upon the mercury in the tubes than it will where the particles of the mercury cohere together; so that in the tubes and between the plates the mercury is drawn by the action of gravity below the general surface, just as it rises above it where the force of adhesion is greater than the force of cohesion. Hence this general law will be found to apply to every case of fluids and solids. If the force of adhesion between the fluid and the substance of the tubes or plates be greater than the force of cohesion between the particles of the fluid, then the fluid will rise in the tubes above the general surface; but if the force of adhesion between the fluid and the substance of the tube be less than the force of cohesion between the particles of the fluid, then the surface of the fluid in the tubes will be depressed. If the force of adhesion be greater, the substances will be wetted if immersed in the fluid and withdrawn; if less, it will be quite dry after immersion; so that from this alone it may always be known whether the fluid will be raised or depressed in the tubes.

*Second.* **Exosmosis and Endosmosis.**—If two fluids of different densities be separated by a thin membrane, the substance of which can be moistened by both, then the two fluids will pass through the membrane and mix together in an inverse proportion to their density. Thus, if a glass containing syrup or any comparatively dense fluid, and covered by a thin membrane, be placed in a large vessel containing water, much more water will pass into the glass and mingle with the syrup, than will pass from the syrup into the water. But if the fluids be nearly equal in density, then that which adheres most to the membrane, and wets it most freely, will pass through it much more rapidly than the other. Thus if a bladder be nearly filled with alcohol and placed in a vessel containing water, the water will pass freely into the bladder, and eventually rupture it, whilst but little alcohol will pass out into the vessel; but if a partition be made with collodion between the fluids, then as this is more freely wetted by the alcohol than by the water, the alcohol will pass freely into the water, whilst but a small quantity of the water will pass through to the alcohol.

**Dialysis** is a term applied to the exosmotic and endosmotic action, when it takes place between fluids of very different chemical activity. Chemically all bodies are divided into two great classes—crystalloids and colloids. The former capable of crystallization, sapid and chemically active; the latter generally insipid, incapable of crystallization, and possessing scarcely any chemical activity, such as gums, jellies, glue, &c.

If two substances of this kind be placed in a shallow tray made of parchment, and then floated on water and allowed to remain, they will be separated; the crystalloid passing through by dialysis into the water, and the colloid remaining in the tray. This presents a ready means generally of separating poisonous substances, which are always chemically active, from the other portions of food with which they may be mixed; and thus offers a means of detecting poisons when mixed with the fluids of the stomach without the intermixture of any other substance, which by its action might interfere with the results of the analysis.

*Second.* If two liquids be mixed together, they are frequently thoroughly incorporated, and do not afterwards separate; whilst others, on the contrary, appear to mix, when agitated, together, but separate partly or entirely when left at rest. Those which remain permanently mixed, if placed in the same vessel, the lighter at the top and the heavier at the bottom, will still diffuse into each other in opposition to gravity.

They diffuse into each other, however, in very different proportions, and generally obey nearly the same law as when divided by a membrane; the most chemically active liquids, such as hydrochloric acid, diffusing with much greater quickness than those of less chemical activity. Gases, too, when separated by a diaphragm, obey the same law as liquids; the lighter gas passing most quickly through the moist diaphragm, if they are equally soluble in the water it contains; but if the denser gas be dissolved more readily than the other, then the heavier gas will pass through in greater quantity; so that if a moist bladder containing oxygen or common air be placed in a jar of carbonic anhydride, the latter, by being more soluble in the water of the membrane, will pass into the bladder so much quicker than the air or oxygen passes out, so as to swell out and finally burst it. When, however, gases are allowed to diffuse into each other without the intervention of a membrane, not only will they pass into each other in opposition to gravity, but, unlike liquids, which do not all remain permanently mixed if left at rest, gases when once mixed together remain so permanently; so that if we take two wide-mouthed jars, one containing hydrogen and the other chlorine, which is more than 35 times heavier, and place the mouths of the jars together, with the hydrogen at the top and the chlorine at the bottom, they will pass into each other, the heavier gas ascending and the lighter descending; and no matter how long they remain, they will not again separate, but remain permanently mixed. The rate, however, of their diffusion is always inversely as the square root of their density; thus the density of oxygen is 16 times greater than that of hydrogen, and consequently hydrogen passes 4 times as quickly into any other gas as oxygen; and generally, the lighter the gas the more quickly will it pass either into a vacuum or into any other gas; and the heavier the gas the more slowly will it diffuse itself. This is the true reason why carbonic anhydride, which is 22 times heavier than hydrogen, accumulates at the bottom of wells, brewers' vats, &c., where it is generated more quickly than it can diffuse itself into the air; whilst at the same time this property of gaseous diffusion will always prevent its accumulation to any injurious extent in the atmosphere, except in places like those where it is generated with great activity. It is by this law of gaseous diffusion that the gases of the atmosphere are equally diffused on the highest mountains and the deepest valleys, and it is this also which prevents the injurious accumulation of carbonic anhydride in large towns, and in the neighbourhood of breweries, large factories, lime-kilns, &c. But not only are liquids and gases diffused into each other, but gases are also absorbed by or dissolved in fluids, and also in solids. Water, for instance, will absorb nearly 500 times its bulk of sulphuretted hydrogen gas, and when it is absorbed to any great extent it is totally destructive of animal life. This gas escapes in large quantities from sewage of all kinds, and the consequence is that water thus impregnated therewith is so poisonous that no fish can live in it; and as the gas also escapes in large quantities from volcanoes, where these are covered by the waters of the sea, it is often destructive to fishes to a considerable distance. The harbour of Callao has been the crater of an extinct volcano, and this gas escapes at times into the harbour in sufficient quantity not only to poison the fish, but also to taint the air of the whole city. It is owing to the quantity of oxygen absorbed in this way by water that fishes are able to exist in it; and as cold water absorbs much more than hot, this is the true reason why our Arctic Seas teem with life, and why the whales always avoid the warm water of the Gulf Stream. Some solids, as charcoal, too, have great power of absorbing noxious gases—the most remarkable of these being charcoal; and hence the great use of charcoal for filters and as a disinfectant; for the injurious gases are absorbed in the pores of the charcoal, and these form new chemical combinations which are devoid of their injurious properties. Carbonic acid gas, or carbonic anhydride, is also absorbed much more readily by water than either oxygen or nitrogen; and this explains what has been previously stated as to its passing much more readily through a moist membrane, and hence causing the bladder, filled with oxygen, to swell out and burst. It is also this readiness of water to absorb carbonic anhydride, especially under pressure, that gives its sparkling effervescing character to champagne, bottled ales, lemonade, seltzer water, &c., which causes the generality of spring and river water to be so much more pleasant to the taste than boiled or distilled water, from which most of the gases have been expelled.

Whilst the action of these molecular forces is felt more or less in nearly all the operations of nature, they are especially important in their influence on the nutrition, growth, and other vital functions of plants and animals.

*First.* In the nutrition and growth of plants. The extremities of the fibrous roots, by capillary action, absorb liquids, and with them the nutritive matter held in solution from the soil; and this fluid gradually becoming denser as it proceeds from the roots upwards, the osmotic action, tending from the more fluid to the denser liquid, will naturally set a current in motion upwards, in opposition to gravity; and thus the nutritive fluid is conveyed from cell to cell, till it reaches the opposite extremities of the growing plant. The descent of the sap is also equally aided by capillary and osmotic action; for in this case, too, it gradually thickens as it descends, causing the action to tend downwards from the leaves, just as it had been upwards in the case of the ascending fluids from the roots. It is owing to this that plants whose roots strike deeply into the ground may continue to grow luxuriantly when the surface is parched with drought; whilst those whose roots are near the surface are entirely destroyed. Another common and familiar example of capillary action is in the ascent of the oil in candles, lamps, &c.; the wicks of these supplying a number of hair-like tubes, by which the combustible fluid is conveyed to the flame as quickly as it is required.

*Second.* In the nutritive and other vital functions of animals, these forces produce results even more important than those they perform in the vegetable kingdom. In all parts of the body, fluids different both as regards density and chemical activity, and also in regard to the quantity of solids and gases they contain in solution, are conveyed by vessels of a porous and elastic character, so that an interchange of these fluids and gases is constantly taking place. Were this not the case, life, as it at present exists, would be an impossibility. It is by these agencies that the nutritive portions of the blood are constantly passing through the thin walls of the capillaries amongst the tissues for their nutrition, whilst at the same time the useless and effete matter from the tissues passes through the same walls, converting the arterial into venous blood. It is also by the same agency that the excess of carbonic anhydride passes from the capillaries of the lungs into the air cells, whilst the oxygen passes back from these cells to purify the blood. When it is considered that the oxygen of the air enters at any one inspiration only into the bronchial tubes, whilst the carbonic anhydride passes into the opposite extremity of the air cells from the capillaries, we see how quick must be the action of gaseous diffusion; that in the short space between one inspiration and another, the air expired must lose 5 per cent. of oxygen, and obtain in exchange 5 per cent. of carbonic anhydride from the blood. It is also chiefly by dialysis that the chemically active portions of the food pass at once into the nutritive system of vessels, through the walls of the stomach, whilst those less chemically active require to be combined with the gastric, pancreatic, and intestinal juices, before they can be absorbed by the lacteals, and serve for the nutrition of the body.

### QUESTIONS ON CHAPTER IV.

1. Give an example of capillary attraction.
2. Why is mercury depressed in capillary tubes of glass whilst water rises above the general level?
3. If a bladder containing syrup be placed in a vessel containing water, what is the result?

4. What is *dialysis*? and where is its force most active?
5. Why does carbonic anhydride accumulate at the bottom of wells, vats, &c.?
6. Why is charcoal valuable as a filter?
7. Explain the rise of the sap in plants.
8. What kinds of fluid are constantly conveyed by the porous vessels of animals?
9. Explain the purification of the blood by the lungs.
10. Explain the use of the capillaries in the nutrition of the body.

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## CHAPTER V.

Forces acting at all Distances. Universal Attraction. Terrestrial Gravitation. Stable, Unstable and Indifferent Equilibrium.

**Forces acting at all Distances.**—Gravitation, or universal attraction, is an attractive force exerted between all bodies, and is always equal to the products of their mass divided by the square of their distance. In the case of spherical bodies they always act upon each other as if their whole mass was collected at their centres. To illustrate this law, then, take the case of two spheres of equal weight, and let their mutual attraction, at the distance of 1 foot, equal 1 unit. If now the mass of one be doubled, and that of the other be trebled, and they be moved to the distance of 2 feet, then their attraction would be $\frac{2 \times 3}{2^2} = \frac{6}{4} = 1\frac{1}{2}$ times the unit. If they had been increased in weight, and their distances unaltered, their attraction would have been 6 units; and if their weight had remained the same, and they had been moved to 2, 3, and 4 feet respectively, their attractions would have been $\frac{1}{4}$, $\frac{1}{9}$, and $\frac{1}{16}$ of the unit. It is this law of gravitation which keeps the whole of our planetary or solar system in its present form; and it is the immense mass of the sun, as compared with that of all the bodies of that system, that keeps them all revolving round it as a centre. Strictly speaking, they do not revolve round the centre of the sun, but round the common centre of gravity of the sun and all the bodies composing the solar system.

**Terrestrial Gravitation,** or **Gravity,** is a particular form of universal gravitation. On account of the great mass of the earth, as compared with that of any bodies on its surface, all bodies free to move are drawn by this force towards the earth's centre, and the force necessary to prevent this is called their gravity, or weight. Now as this force decreases with the square of the distance from the centre, it follows that bodies removed farther from the earth's centre will weigh less than those near; and that, as the earth is not a complete sphere, but bulges out at the equator and is flattened at the poles, so bodies being nearer the earth's centre at the poles will weigh more than they do at the equator, where they are further distant. But as the rotatory motion of the earth at the equator is more than 1,000 miles per hour, and as this rotation has a tendency to throw off bodies from the earth's surface, and acts in opposition to gravity, this also tends to make the weight of bodies at the equator less than at the poles.

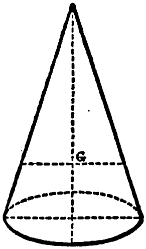
It is calculated that about $\frac{1}{289}$ of the earth's attraction, or of the force of gravity at the equator, is spent in preventing bodies from being thrown off; so that, on this account alone, a body weighing 289 lbs. at the poles will only weigh 288 at the equator; but when its greater distance from the earth's centre is taken into account, it is known that, were the earth at rest, the force of gravity at the poles to that at the equator is nearly as 157 to 156; so that, owing to the combined action of these forces, a body weighing 289 lbs. at the poles would not weigh much more than 286 at the equator.

It is owing to the rotation of the earth, and the decreased action of gravity at the equator, that the earth is not a complete sphere, but bulges at the equator, and is flattened at the poles. As all bodies near the earth fall towards the centre, so all bodies near the moon fall towards the centre of the moon; and if a body were placed between the moon and the earth, in such a position that the mass of the moon, divided by the square of its distance from it, equalled the mass of the earth divided by the square of its distance therefrom, it would remain poised between them, without any tendency to move towards one more than the other. It follows from this that bodies decrease in weight as they are elevated above the level of the sea; so that if a mass weighing 1,000 lbs. were carried to the height of 4 miles, it would only weigh 998 lbs.; and were the moon not in existence, and a body that on the earth's surface weighed 3,600 lbs. put in its place, the force of the earth's attraction upon it would only be equal to 1 lb.; for as the moon is distant nearly 60 times the distance between the earth's centre and surface, therefore $\frac{3{,}600 \text{ lbs.}}{60^2}$, or 1, would be the force of gravity at that distance as compared with its action at the level of the sea. The force of gravity is greatest at the level of the sea, and decreases towards the centre directly as the distance from the surface increases; and at the centre it ceases to act; so that could a body be placed in the centre of the earth, free to move in any direction, it would remain without any tendency to move, as regards the earth, in one direction more than in another.

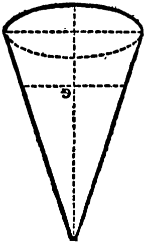
It has been previously stated that in a sphere gravity acts as if the whole mass were collected together at its centre, and no matter how irregular the shape, or unequal the density of any body, gravity always acts upon it as if its whole mass were collected at one point. This point is called the centre of gravity of the body, and if this point be supported the whole body will remain at rest. In regular bodies of uniform density the centre of gravity can easily be determined by calculation. Thus, in a rod of uniform thickness, this point is exactly midway between the ends. In a triangular disk or plate of uniform thickness, and placed on one edge, it is at one-third the height; and in a pyramid or cone, placed upon its base, at one-fourth the height. Sometimes the centre of gravity is not in the mass at all, as in the case of a metallic or other ring, where the centre of gravity is at the centre of the circle of which the ring forms the circumference. In all irregularly-shaped bodies, or bodies of unequal density, it is easy to determine the position of the centre of gravity by experiment. To do this it is only necessary to suspend the body from a fixed point in two different positions, and then draw a vertical line through the body in these positions. The point where these lines intersect is the centre of gravity of the body.

The centre of gravity of any body being supported, it will remain at rest, or in equilibrium, in any position; but this equilibrium may be of very different kinds, and those differences are generally styled, **stable, unstable,** and **indifferent** equilibrium. The equilibrium of a body is said to be **stable** if the body cannot be moved without raising the centre of gravity in opposition to the attraction of the earth; and this stability is greater in proportion to the weight of the body, and the height to which the centre of gravity must be raised when the body is moved.

All bodies suspended entirely from fixed supports are in stable equilibrium, and their stability increases with the distance of the centre of gravity beneath the point of support. Generally, also, the wider the base on which any body rests, and the nearer its centre of gravity is to the centre of the base, the greater its stability, as the centre of gravity must be raised higher before it can be overturned.



STABLE EQUILIBRIUM.



UNSTABLE EQUILIBRIUM.

**Unstable Equilibrium** is when the body is so placed that any alteration of its position causes the centre of gravity to descend. This is obviously the case of a cone supported on its apex, of a rod or oval supported on its end; and hence the difficulty of keeping those bodies in such position, and the skill necessary to keep them balanced in them; since every motion of the body requires a corresponding movement of the point of support, to prevent it from falling. It follows, however, that contrary to what would at first seem probable, the longer the rod or cone thus balanced is, the easier it is to keep it in equilibrium.

**Indifferent Equilibrium** is when on movement of a body the centre of gravity neither rises nor falls, but moves in a horizontal plane. This is the case when a sphere is placed on any horizontal surface, since in whatever direction it moves the centre of gravity neither rises nor falls. When the path of the centre of gravity moves in a curved line, there will be two points of equilibrium—one point of stable, where the curve occupies its lowest, and one of unstable, where it occupies its highest point.

### QUESTIONS ON CHAPTER V.

1. What is gravitation? and what is the law of its decrease in force?
2. Why do bodies weigh less at the earth's equator than at its poles?
3. What effect has the revolution of the earth on its axis on the weight of bodies at the equator?
4. Where is the force of gravity greatest, and how does it decrease as we ascend above or descend below the level of the sea?
5. What is the force of the earth's attraction on the moon as compared with its force at the level of the sea?
6. How does gravity act on a sphere?
7. Define the centre of gravity, and state how it may always be determined.
8. Define stable equilibrium.
9. What is the state of equilibrium of bodies suspended from fixed supports?
10. Give examples of *unstable* and indifferent equilibrium.

## CHAPTER VI.

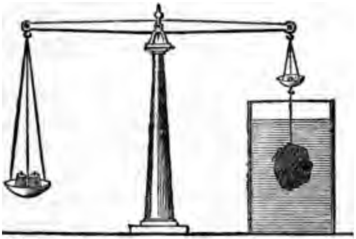
**Weight of Bodies. Specific Gravities. Standards of Comparison for Solids, Liquids, and Gases. Methods of Determining Specific Gravities of Bodies. Hydrometer.**

As it is the force of the earth's attraction that gives gravity or weight to bodies, and as it exerts this force with far more effect on some than on others in proportion to their volume, so it follows that the same volume of different bodies will vary in their weight. These variations in the weights of the same volume of bodies are called their specific gravities. As these gravities are relative only, it is necessary to fix on some unit of comparison, and to refer all other bodies to this unit; for though we speak of bodies as heavier or lighter than each other, in a general way, when we wish to state this accurately we always refer them to this common standard.

For fluids and solids, water is taken as the standard; and as a cubic foot of water, at a temperature of 60°, and a pressure of the atmosphere equal to 30 inches of mercury, weighs 1,000 ounces; so from this the weight of any other body whose specific gravity is known may be easily determined. As the density of water is greatest at the temperature of 39·2° Fahr., or 4° C., so in France, and generally on the Continent of Europe, this temperature is taken as the standard, not only for calculating specific gravities, but also for the standard of weight for all purposes. Their unit of measure is called a metre, and the weight of a cubic centimetre of water, at a temperature of 4° C., and an atmospheric pressure of 760 millimetres, is called a gramme, by the multiplication or division of which all their weights are derived. But though water is the best standard with which to compare all other liquids and solids, yet for gases it has been usual to take air as a standard, and to speak of the density of other gases in relation to air. There are, however, many advantages in taking hydrogen as the standard, for then the atomic weights give at once their specific gravities as compared with hydrogen; and as 11·19 litres of hydrogen just weigh 1 gramme, the weight in grammes of 11·19 litres of any other gas gives at once its specific gravity.

As the earth is surrounded by a gaseous envelope called the atmosphere, the specific gravity of which near the earth's surface is nearly 772 times less than that of water, the action of the earth's attraction upon this must be for equal volumes much less than it is for any liquid or solid body; and therefore a stone, a drop of water, or any other solid or liquid body, falls to the earth through the air because its weight in proportion to its volume is much greater than that of the air; but if a body, such as a balloon, be filled with pure hydrogen, heated air, or common gas, it will rise in the air because the force of gravity on the air is greater for the same volume than it is for the balloon. The rising of a balloon in the air is therefore just as much owing to the attraction of the earth as the falling of a stone; the one rising because its specific gravity is less, and the other falling because its specific gravity is greater than that of the air. The same principle applies also to bodies sinking and rising in water. Thus a stone or a piece of iron will sink in water, whilst a cork or any other light wood will rise, just because the specific gravity of the stone or iron is greater whilst that of the cork or light wood is less than that of the water.

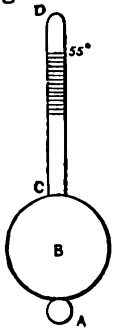
Strictly speaking, we rarely obtain the exact weight of any bulky and light substance weighed in air, but it always appears to weigh less than it really does by the difference between the weight of the air occupied by it and that occupied by the substance used as a weight. This may be proved by balancing at the ends of a well-balanced lever a piece of platinum and a hollow sphere of, say, 10 or 12 inches in diameter. If after they have been equally balanced in air they are placed under the receiver of an air-pump, and the air exhausted, it will be seen that the sphere sinks, showing that it is actually heavier than the platinum by which it was balanced in the air; and by adding to the platinum a weight equal to that



METHODS FOR DETERMINING SPECIFIC GRAVITY OF SOLIDS.

volume of air displaced by the sphere, and then placing them in the receiver and producing a vacuum, it will be found that they exactly balance each other. If a body be weighed in air and then in water, it will be found to lose a certain part of its weight, and the part lost is always the weight of a volume of water equal to its own bulk. As water forms the standard of specific gravity for fluids and solids, this affords an easy method of determining the specific gravities of all solids heavier than water, providing the water does not dissolve them. It is only necessary to weigh the substance in air and then in water, and divide its weight in air by the amount it loses by being weighed in water, and the quotient will be its specific gravity. Thus, if a body weigh 12 lbs. in air and 10 lbs. in water, then, as it loses 2 lbs. weight, it follows that a volume of water equal in bulk to the body would weigh 2 lbs., and $\frac{\text{its weight in air 12 lbs.}}{\text{its loss in water 2 lbs.}} = 6$, which is therefore the specific gravity of the body. If, however, the substance be soluble in water, it must then be weighed in some liquid such as oil or alcohol in which it is not soluble, and its specific gravity determined in the same way with regard to that liquid, and then the result multiplied by the specific gravity, if the liquid in which it was weighed will give its specific gravity as compared with water. Thus, if a body in air weighed 15 lbs. and in alcohol 10 lbs., then $\frac{15}{5} = 3$ for its specific gravity as compared with alcohol, and this multiplied by 792, which is the specific gravity of alcohol, would give 2·376 for the specific gravity of the body.

To determine the specific gravities of fluids, an instrument called a Hydrometer is generally used. These instruments are of different forms, but they all depend upon the principle that a floating body always displaces a quantity of fluid equal to itself in weight, and consequently, that any solid of known weight will sink deeper in a lighter than in a heavier liquid. These instruments are much used in the Excise, by dealers in spirits, &c., for as the specific gravity of alcohol is only 0·792, any addition of water to it will increase its specific gravity, and consequently the hydrometer will sink lower in proportion to the strength of the spirit. In the case of acids, milk, &c., the density of which increases with their strength or purity, the same instrument, though differently graduated, is used to determine the strength or purity of the liquid to be tested. The specific gravity of fluids may also be obtained by balancing at the ends of a delicate scale beam, by a weight, a bottle that will exactly contain a known weight of water, and then dividing the weight of the liquid whose specific gravity is required by the weight of water the bottle will contain. Thus, if the bottle hold 10 ounces of water, and being filled with olive oil, the specific gravity of which is required, it will be found to weigh 9·15 ounces, and $\frac{9·15}{10·00} = ·915$, which is therefore the specific gravity of the oil. The specific gravities of gases may be obtained in a similar way, by carefully weighing a large globe full of air, and



HYDROMETER.

then, after exhausting the air, filling it with the gas whose specific gravity is required. Then the weight of the gas, divided by the weight of the air, will give the specific gravity of the gas compared with the atmospheric air, as in the case of fluids it gives the specific gravity as compared with water. Thus, if the difference between the weight of the globe when full of air and when exhausted by the air-pump was 2 grains, and that this difference in the case of any gas whose specific gravity was required = 3 grains, then $\frac{3}{2} = 1{\cdot}5$, the specific gravity required. The importance of being able to determine specific gravities in the cases of spirits, acids, milk, &c., as a means of preventing adulteration and fraud, are well known. The ordinary method of testing gold coins, too, depends upon the same principle, for as gold is by far the heaviest metal excepting platinum, so any counterfeit sovereign equal to it in weight must exceed it in bulk. Any coin, therefore, equal in weight, and passing through the same space as would just admit a sovereign, may be fairly concluded to be genuine.

### QUESTIONS ON CHAPTER VI.

1. What gives weight to bodies?
2. What is meant by specific gravity?
3. Mention the different standards of specific gravity in England and France.
4. What standards are generally fixed upon for gases? Why is hydrogen the best?
5. Why does a balloon rise in the air?
6. What prevents us ordinarily obtaining the exact weight of any bulky substance?
7. What is a hydrometer?
8. How can a hydrometer be used to test the purity of spirits?
9. Explain the principle of the common tests for genuine gold coins.
10. What other methods may be used for determining the specific gravities of fluids or gases?

# CHAPTER VII.

## The Laws which Regulate the Descent of Falling Bodies. Pendulums, and the Laws which Regulate their Periods of Oscillation.

THE attraction of the earth, as has been stated, differs at different places on its surface, and generally increases with the latitude, being least at the equator and greatest at the poles. It is also a constantly-accelerating force, and bodies under its influence move with constantly-increasing speed till brought to a state of rest by some opposing force. This force, in the latitude of London, would give to a falling body in 1 second a velocity of 32·19 feet, in 2 seconds 64·38 feet, in 3 seconds 96·57 feet, &c.; for as gravity acts constantly, and gives a velocity from a state of rest of 32·19 feet in a second, in the next second it will also give an increase of 32·19, which, added to 32·19 it had at the commencement of the time, will give 64·38 as the velocity at the end of 2 seconds, 96·57 at the end of 3 seconds, &c. Generally, therefore, if $s$ = time in seconds, then $s \times 32{\cdot}19$ will give the velocity of a falling body at any period of its progress.

But as a body falling from a state of rest till it acquired a velocity of 32·19 feet will have a mean velocity of 16·095, being that it would have at the end of half a second, so its mean velocity in the next second would be 48·285, in the third 80·475, and generally as 16·095 multiplied by 1 for the first, 3 for the second, and 5 for the third, 7 for the fourth, and so on by the odd numbers, which are one less than twice the number of seconds during which the body has fallen: thus its mean velocity in the seventh second will be $2 \times 7 - 1$, or $13 \times 16{\cdot}095 = 209{\cdot}235$ feet, which is the space through which a body would fall in the seventh second. The spaces fallen through from a state of rest in any number of seconds will always equal 16·095 feet × square of the time in seconds. In the first second it falls 16·095, in the second 48·285, and $48{\cdot}285 + 16{\cdot}095 = 64{\cdot}380$, or $16{\cdot}095 \times 2^2$; so in the third second it will fall through 80·475, and 80·475 + 64·380 = 144·855, or $16{\cdot}095 \times 3^2$, and so on any number of seconds.

Now, as the force of gravity during one second produces a velocity of 32·19 nearly, and in half that time $\frac{32{\cdot}19}{2}$, or 16·095, let $s$ = space or height from which a body falls, $t$ = time in seconds, $v$ = velocity, and $16{\cdot}095 = \frac{g}{2}$, or half the velocity at end of one second, then the following formulæ will enable any one of these to be found when the others are given:—

(1). Thus, $s = t^2 \times \frac{g}{2} = t^2 \times 16{\cdot}095 = \frac{v}{2} \times t$.

(2). $v = t \times g = t \times 32{\cdot}19$.

(3). $t = \frac{v}{g} = \frac{v}{32{\cdot}19}$.

Substituting the value of $t$ in (3), in formula (1) it becomes—

(4). $s = \frac{v}{g} \times \frac{v}{g} \times \frac{g}{2} = \frac{v^2}{2g}$, and $v^2 = 2g \times s$.

If a heavy body, instead of falling perpendicularly, fall down an inclined plane, a series of inclined planes, or along a curved surface, its velocity at any point will be the same as if it had fallen perpendicularly down the height of the plane or curve.

A simple pendulum is a heavy particle suspended from a fixed point by a wire or string, and allowed to oscillate backwards and forwards. If it met with no resistance it would, in moving downwards from any position higher than its lowest point, gain momentum enough to carry it as far above its lowest point on the other side, and would thus go on oscillating backwards and forwards for any length of time. But as the air and the friction at the point of suspension each offer a certain resistance to its progress, so it would soon be brought to rest were not some force given to it, sufficient to overcome these resistances. In the case of clocks, time-pieces, &c., this force is generally given either by a weight or by the force of a spring, the uncoiling of the spring or the descent of the weight being regulated by the motion of the pendulum itself. If the amplitude of the oscillations be small they are performed in equal times, and those times are always inversely as the square root of the length of the pendulum. Thus, if 3 pendulums of the lengths of 1, 4, and 16 feet each, were allowed to oscillate in small arcs, it would be found that the first would make 4, and the second 2, whilst the third made 1 oscillation.

The accelerating force that makes the pendulum descend is evidently the force of gravity acting upon it at that point, and therefore the number of oscillations of a pendulum in any given time will be a measure of the force of gravity at that place. It has thus been practically determined that, as stated previously, the force of gravity is least at the equator and increases with the latitude towards the poles; and consequently the length of a pendulum that performs such oscillations in one second will be less at the equator and greatest towards the poles. The length of the seconds pendulum in the latitude of London is 39·1393 inches, whilst at Spitzbergen, according to General Sabine, it is 39·21464 inches, and at Sierra Leone 39·01954.

### QUESTIONS ON CHAPTER VII.

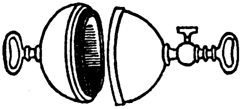
1. Through what space will a body fall in one second in the latitude of London?
2. Through what space would a body fall in five seconds?
3. Through what space must a body fall to get a velocity of 3,219 feet per second?
4. What would be the comparative number of oscillations of two pendulums, one sixteen and the other sixty-four feet in length?

## CHAPTER VIII.

The Atmosphere: its Pressure. Boyle's and Marriott's Law. The Magdeburgh, Torricelli's and Pascal's Experiments. Winds: Permanent, Periodical, and Variable.

THE atmosphere is that gaseous envelope that surrounds the earth on all sides, rotates with it daily on its axis, and also accompanies it in its journey round the sun. Dry air consists by volume of nearly 79 nitrogen and 21 oxygen, and by weight of 77 nitrogen and 23 oxygen. It also contains a small quantity of carbonic anhydride and traces of ammonia and various other gases. Along with this is also a varying proportion of aqueous vapour; this proportion being generally much greater in hot countries than in cold, and also much greater over islands and near the coast than it is in the interior of continents. These different gases are not arranged in the order of their weight, or else we should have near the earth a thin layer of carbonic anhydride, then a much thicker one of oxygen, over this a still larger one of nitrogen, and above all one of aqueous vapour. The atmosphere, like all gases, obeys the laws of gravitation, and, as that nearest the earth's surface must sustain a pressure of the entire column above it, its density is greatest near the earth's surface, where it sustains an average pressure of about 15 lbs. on every square inch, and its density decreases as we ascend; so that at the height of 3 miles it is only about $\frac{1}{2}$, at 6 miles $\frac{1}{4}$, and at 15 miles only about $\frac{1}{30}$ of what it is near the surface. The law which regulates the volume of gases is known as that of Boyle or Marriott, and is, that the volume of a gas is always inversely as the pressure, *i.e.*, that, as the air near the surface occupies a certain space with a pressure of 15 lbs. on the square inch, if the pressure be increased to 30 lbs. it will only occupy half the space, if to 45 lbs. only one-third the space, and if to 60 lbs. one-fourth the space, &c. The pressure of the atmosphere is equal to a column of mercury of the height of nearly 30 inches, to one of water of nearly 34 feet, and to a column of air of the density at the earth's surface of a little more than 5 miles; but, as the air decreases rapidly in density, and becomes more and more rare as we ascend, there must come a height where the atmosphere will cease altogether, or become too rare to produce any sensible effects. It has till lately been considered that at a height of 45 or 50 miles the force of the earth's attraction would overcome the repulsive force of the molecules of the atmosphere, and that therefore it did not in any sensible form extend beyond that height. It has, however, lately been proved that at a height of 150, or even 200 miles, it produces sensible action on meteors and light, so that the probability is that it gradually thins away into that imponderable form of matter generally called *ether* which pervades all space. If the law of Marriott continue to act to an unlimited extent, a cubic inch of air from the surface of the earth would be expanded, at a distance between the earth and the moon, where their attractive force is equal, so as to occupy a far larger space than the whole atmosphere has generally been considered to occupy; on the other hand, if this law continued downwards, at a depth of about 46 miles the atmosphere would be equal in density to mercury.

That the pressure of the air is a reality is easily proved by an experiment first performed at Magdeburg. Two hollow hemispheres, to one of which is attached a contrivance for exhausting the air, are placed together, and then, by means of an air-pump, the air inside the hemispheres is exhausted. It is then found that a



*considerable* force is necessary to separate them; and as *this force is* necessary in whatever position the hemispheres are placed, it not only proves the reality of the pressure of the air, but that it is exerted in all directions. When the air is readmitted inside the hemispheres they are found to separate again very easily, showing that the force required when they were exhausted of air was not due to *cohesion* but to atmospheric *pressure.*

The following experiment, however, will, in a very simple and convincing manner, prove that the atmosphere presses upwards as well as downwards. Take an ordinary tumbler, fill it with water, place a piece of card over it, and, keeping the card in its place, invert the tumbler. The hand may then be removed, and the water will be kept in the glass, in opposition to its gravity, by the upward pressure of the air upon the card.

The actual force of this pressure at the surface of the earth was demonstrated by Torricelli, who, having a glass tube of about 3 feet long, closed at one end and filled with mercury, placed the open end in a vessel containing mercury, and then found that the column of mercury in the tube stood at a height of nearly 30 inches, whilst the space above this from whence the mercury had fallen was emptied of air and formed a kind of vacuum, known from this discovery as that of Torricelli. On making an opening in the closed end of the tube, and admitting the air, the mercury fell to the level of that in the vessel in which the tube was placed; thus proving that it had been previously supported in the tube by the atmospheric pressure. To be more certain, however, that this was the true solution of the phenomenon, Pascal, knowing that the atmospheric pressure would decrease with the height above the level of the sea, had the same experiment performed on the top of the Puy-de-Dôme, in Auvergne, and found, as he expected, that the column of mercury supported in the tube was 3 inches lower than that supported at the level of the sea. If a tube of glass about 40 feet long be similarly filled with water, and its open end placed in a vessel full of that liquid, the column in the tube will descend to the height of 33 or 34 feet, and there remain, unless the air be admitted into the upper end of the tube, and then it will descend to the level of the fluid in the vessel in the same way as was done in the mercury. Now, as the specific gravity of mercury is 13·59, this, multiplied by 30 inches, the height of the column of mercury, will give the height at which the water stands in the tube; thus again showing that the two phenomena are owing to the same cause.

Were the atmosphere always in a state of repose the law of gaseous diffusion would tend ultimately to keep it in a state of purity, but, as this diffusion requires time, and as the causes which tend to vitiate the air, especially in populous neighbourhoods, are powerful and active, the movements of the air by winds, storms, &c., are very necessary influences, the tendencies of which are all in the same direction. Winds of all kinds arise generally from variation in the temperature of the air. Wherever the temperature of the air is increased it expands, and, becoming lighter, ascends, causing a current of colder and denser air which comes to take its place. In the equatorial portions of the earth the air, heated by the direct rays of the sun, becomes lighter, and, rising up, a current of colder and denser air from the polar regions comes towards the equator to supply its place. These currents would cause a northern current from the north pole, and a southern one from the south pole, towards the equator; but, owing to the rotation of the earth on its axis, these currents are converted into a north-eastern current on the north side and a south-eastern current on the south side, there being between the two a shifting zone or region of calms. As these currents blow steadily during all the year over the greatest portions of the Atlantic and Pacific Oceans to a distance of 25° to 30° on each side of the equator, they are called permanent winds, and, because of their great importance to trade and commerce, especially before the discovery and general use of steam, they are known as the *Trade Winds.* Another important class of winds are called periodical, from their blowing regularly at stated periods. The most important of these are the *Monsoons*, which blow in the Indian and western portions of the Pacific Ocean, blowing regularly from the south west from April to October, and from the north-east from October to April. In this class of winds may also be reckoned the land and sea breezes which regularly, in many parts of the world, but especially in the tropical islands of the Pacific, blow from the sea towards the land during the day and from the land towards the sea during the night.

In addition to these, violent and sudden winds often arise within the Torrid Zone during the hottest part of the year. These winds are known as cyclones or hurricanes when they occur in the West Indies, and as typhoons when they occur in the Indian Ocean and China Seas. Though these, from their extreme violence, are often the cause of much loss of life and valuable property, yet they tend in those hot districts to purify the air and to remove from it many sources of impurity, prejudicial to animal and vegetable life. In addition to the movements of the air called winds, the atmosphere has its tides, which are as regular in their recurrence as those of the ocean ; and from the rotatory action of the earth, and the decrease of gravity near the Equator, there is no doubt that the atmosphere extends much farther at the Equator than it does in the neighbourhood of the Poles.

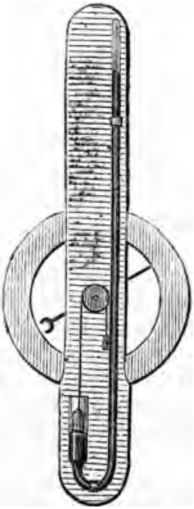
## QUESTIONS ON CHAPTER VIII.

1. What is the atmosphere? and of what does it consist?
2. Where is the greatest amount of vapour contained in it?

3. Explain Boyle and Marriott's law.
4. To what height is the atmosphere supposed to extend?
5. What would be the density of the air at a depth of forty-six miles?
6. Explain the experiments illustrating the pressure of the air, and describe the experiments of Torricelli and Pascal.
7. Explain the origin of winds.
8. Describe and account for the trade winds and monsoons.
9. Explain the beneficial effects of winds and storms. Where are the latter most frequent?

## CHAPTER IX.

Instruments Depending for their Use on the Properties of the Atmosphere. The Barometer, and its Use as a Weather Glass. The Pump and Syphon.

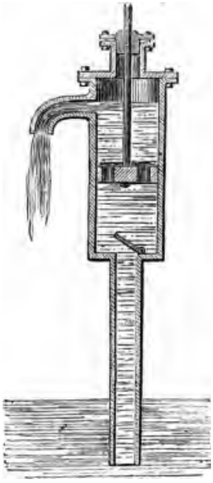


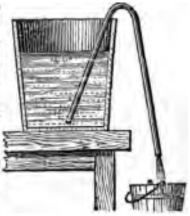
**The Barometer.**—This, as its name implies, is an instrument used for measuring the gravity or weight of the air. In its simplest form it consists of a tube 33 or 34 inches in length, and closed at one end, and the open end placed in a vessel containing mercury. As the air presses freely upon the mercury in the vessel whilst that in the tube is nearly quite free from that pressure, so the length of the column in the tube will vary with the variation of the atmospheric pressure. As we can easily conceive the whole of the atmosphere to consist of a number of thin layers placed upon each other, it is evident that the lowest will sustain the pressure of the whole of those above it; the next, of all but one; the next, of all but two, and so on, each upper layer *bearing* a less pressure than the one below it. It appears easy therefore to understand how the barometer may be used to determine the height of mountains; and though the calculations, to be exact, require great care, yet an approximation can easily be made where the distance is not great, by allowing a height of 800 feet for each inch the column of mercury descends beneath its height at the level of the sea. But the barometers in most common use are the syphon or wheel barometers. In these the tube is bent upwards, and the part bent up to which the air has access has a float, which being partly counterpoised by a weight, is connected therewith by a pulley. To this pulley an index is attached, and this index points out the rise or fall of the mercury. A great height of the column of mercury is considered to betoken fine weather, a medium height, variable, and a low column wet or stormy weather; and from these indications of the state of the weather being marked on the barometers they are popularly described as weather-glasses. Though these indications must be often incorrect, and must be altogether wrong under very different conditions of climate and altitude, yet, when proper allowance is made for these varying circumstances, there is more truth in their indications than is generally supposed. It seems at first sight unreasonable to suppose that there should be any intimate connection between the weight of the atmosphere and the fall of rain; but if the following facts be carefully considered this connection will, I think, be clearly established.

*First.* The different gases that make up the atmosphere are of very different specific gravities. Thus, carbonic anhydride is 22; oxygen, 16; nitrogen, 14, and the vapour of water 9 times heavier than an equal volume of hydrogen. The quantity of carbonic anhydride being only 3 to 5 parts in 10,000, it is altogether too small to affect materially the weight of the air; and as the oxygen and nitrogen in dry air are always mixed in the same proportion, so no variations can arise from an atmosphere of dry air but such as arises from a variation in its mass, as by winds, tides, &c. But dry atmospheric air has very different powers of sustaining in an invisible form the vapour of water. At a freezing temperature it can only thus retain $\frac{1}{160}$th of its weight; at 59° Fahr., $\frac{1}{80}$th; at 86°, $\frac{1}{40}$th; at 113°, $\frac{1}{2}$; and at 140°, $\frac{1}{10}$th. Now the weight of dry air as compared with aqueous vapour being about 5 to 3, it follows that the greater proportion there is of vapour mixed with the dry air, the lighter it will be; and as the probability of rain falling is proportionate to the amount of vapour in the air, there is, consequently, a greater probability of rain in proportion to the lightness of the atmosphere, as that very lightness is caused by the vapour it contains. This large amount of vapour held by hot air, and its consequent lightness, account for the fact that, though there is no doubt that the atmosphere extends considerably further at the Equator than it does towards the Poles, yet its pressure is much lower at the Equator than it is at a distance of 30° or 40° from it. As vapour passes into the air most freely from large bodies of water, and as there is much more water in the southern than in the northern hemisphere, so this also accounts for the well-known fact, that the atmospheric pressure at equal latitudes is very much less in the southern than it is in the northern hemisphere. It also equally explains the fact, that this pressure is generally less on islands, and near the coast, than in the centres of large masses of land, and is especially less when the winds come from the direction of the oceans, as then they are likely to contain much more vapour.

Another instrument depending for its use on atmospheric pressure is the *common*, or SUCTION PUMP. This consists essentially of a tube placed at its lower end in contact with the fluid, and having, closely fitting this tube, a piston, furnished with a valve opening upwards to allow the fluid to pass through it when the piston descends, and closing to prevent its return when the piston ascends. During the ascent of the piston, a vacuum of a more or less perfect kind would be formed under the piston were it not that the pressure of the air forces the water up the tube after the piston, and when the piston descends the valve opens and the water flows through and ultimately passes out at a spout near the top of the tube.

As this pump depends for its action on atmospheric pressure, it cannot, by mere exhaustion of the air in the tube, cause the water to rise higher than about 30 feet, and this height of course decreases as the elevation above the level of the sea increases. If the piston worked completely air-tight, the column of water could be raised nearly 34 feet, this being the length of a column of water equal in weight to a column of mercury of the height of 30 inches; but as a perfect vacuum cannot be obtained in practice, water can rarely be raised by mere suction more than 30 feet. If, however, a valve opening upwards be placed at a lower level than this, water can still be raised to any required height; but this is not owing to atmospheric pressure, the water being simply lifted by the ascent of the piston. Pumps which raise the water partly by atmospheric pressure and partly by lifting are generally called lifting pumps. If the piston be solid, and on its descent, instead of allowing the water to rise through a valve, force it down before it into a second tube furnished with a valve opening upwards to allow the water to enter, but which will not allow it to return, then it is called a force-pump, and water can, of course, be raised thereby to any required height.


SUCTION PUMP.


SYPHON.

The **Syphon**, which is of such common use in emptying casks, barrels, &c., consists of a bent tube having one leg longer than the other. If this be filled with fluid, and then the shorter end placed in the vessel to be emptied, the fluid will have equal atmospheric pressure at each end of the tube; but as the weight of the column in the longer tube is greater than that in the shorter, it will fall by gravity, and the pressure of the air on the liquid in the vessel to be emptied will compel the fluid therein to enter the shorter end of the tube as quickly as it descends fromthe longer.

### QUESTIONS ON CHAPTER IX.

1. Explain the construction of the barometer.
2. Why can it be used to determine the height of mountains and foretell rain?
3. Which are the heaviest and which the lightest constituents of the atmosphere?
4. How does the temperature of the air affect the quantity of vapour it can contain?
5. Whether is the barometric pressure greater in the northern than in the southern hemisphere? Give the reasons for this difference.
6. To what height can water be raised by an ordinary pump?
7. Explain the action of *forcing* and *lifting* pumps.
8. What is the use of the syphon?

# DIVISION II.

## CHAPTER X.

Sound: Noise, Music. Waves of Sound Medium of Propagation. Velocity in different Media. Intensity. Reflection. Reflection of Sound. Echoes: Whispering Galleries.

WHEN an impulse is given to the air or any other elastic body, causing it to assume a vibratory motion of sufficient rapidity, sound is produced. Sounds are of two kinds—noise and music. Noise arises from irregular, harsh or discordant sounds, such as firing of a pistol, the scratching of a nail over a rough surface, or the passing of a wheel over a rough road. Music, on the contrary, arises from regular vibrations, such as those produced by striking the strings of a harp or pianoforte. The only essential of a musical sound is, in fact, that the undulations producing it should be of sufficient rapidity, and the impulses follow each other at regular intervals. When an impulse is given to an elastic body, its molecules have a tendency to return to their original condition of equilibrium, but, from the property of inertia, they can only do this by making a series of oscillations, or vibrations, on each side of this position, the amplitude of these vibrations decreasing till they gradually cease. Thus, if a pendulum be moved from its state of rest it will oscillate backwards and forwards on each side of the point of suspension, each oscillation being less than the preceding one, till at last it comes to rest in equilibrium exactly under its point of suspension. If a stone be dropped on the surface of smooth water, it will displace a certain quantity and heap it up around it; and this raised portion of water will be seen to widen out in a larger and larger circle, its height becoming less and less as the circle is increased, till it becomes too small for its progress to be traced. Between this outer circle and the original cause of disturbance will be found a series of lesser circles, where the water is elevated above, and between these spaces where it is depressed below its general level.

The distance between one elevation and another is called the length of the wave, its elevation above the general level, its *height*, and its depression below that level, the *depth*, and the distance from its position of rest to which any individual particle of water is driven is called its amplitude. The amplitude is always proportionate to the force of the original impulse, and measures the intensity of the sound; and as the amplitude increases with the distance from the original impulse so does the intensity of the sound; this always decreasing inversely as the square of the distance when the sound is propagated in open air. If, however, the sound be propagated along smooth tubes then the intensity decreases only as the distance, and hence tubes are now very commonly employed as a means of communication between distant parts of buildings, as by their means conversation may be carried on between persons at a distance, where through the open air this would be quite impossible.

Sound can only be propagated by elastic bodies, and the quickness with which it is propagated depends on this elasticity; the hindrance to its propagation being the density. It therefore proceeds with the greatest velocity through substances whose elasticity is greatest in proportion to their density; and if the density of any substance be increased, whilst its elasticity remains the same, it will then proceed through it slower; whilst if its elasticity be increased, the density remaining the same, it will proceed through it with greater velocity. Sound passes through gases having the same elasticity with a velocity inversely as the square root of their density. Thus, as the density of oxygen is 16 times that of hydrogen, sound travels 4 times quicker through hydrogen than through oxygen; travelling through oxygen at the rate of 1,041 feet, and through hydrogen 4,164 feet per second; whilst through carbonic anhydride, which is 22 times denser than hydrogen, it passes with a velocity of $\frac{4164}{\sqrt{22}}$, or nearly 886 feet per second. Its velocity through air naturally depends upon the temperature, for an increase of temperature *decreases* the density without decreasing the elasticity. At a freezing temperature this velocity is 1,090 feet per second, and the velocity increases 2 feet for every increase in 1° C. to the temperature. Hence at 10° C. its velocity will be 1,110 feet per second, at 15° C. 1,120 feet, &c. At the same temperature the velocity of sound in air is the same, whatever be its density; and the velocity of sound at the highest elevations reached by man is the same as at the level of the sea, when allowance is made for the difference of temperature. From what has been stated previously respecting the density of the vapour of the atmosphere, it will be understood that sound would travel more quickly through the vapour atmosphere than through dry air; and when there is a sufficient quantity of vapour in the air to transmit sound, two distinct reports of guns, cannons, &c., are commonly heard; the first through the vapour atmosphere, the second through the dry air.

As light is comparatively instantaneous, and sound travels at a known rate, the difference between seeing the flash of lightning and hearing the thunder gives us pretty accurately the distance of the electric discharge; and we can also, by noting the time between seeing the flash of a cannon or gun and hearing the report, determine the distance at which they are fired. In water the elasticity, as compared with its density, is nearly 16 times that of air; so that sound travels 4 times as quickly through water as through air. The elasticity of solids, as compared with their density, is—except in the case of lead, through which sound travels slower than through water—much greater than that of liquids; so that sound travels 3 or 4 times as quickly through iron and different kinds of wood as it does through water. It is on this account that, if a long tube be struck with a hammer, two sounds can be heard at the opposite end; the first through the metal tube, the second through the air. This can also be heard in the blasting of rocks, &c.; and at the great explosion of gunpowder at Erith, three distinct shocks were perceived by persons in London, on the banks of the Thames: one through the earth, the second by the water, and the third through the air. It follows, too, that sounds travel further through substances which convey them with the greatest velocity; hence, by applying the ear to the rails, a train can be heard long before its sound can be detected in the open air; and by connecting a rod of wood or steel with a musical-box, its sound can be well heard in a room much too distant for its sound to be heard through the open air.

Sounds originating in a dense can be heard well in a rare medium. Hence, sounds originating in the vibrations of a solid will pass readily into a liquid; and those originating in a liquid will pass readily into, and *be heard in air*; also, sounds originating in dense air *will pass readily* into and be heard in rarer air. But sounds originating in a rare medium cannot readily be heard in a dense one, and cannot either originate in or pass through a vacuum, as may be proved by the following experiment.

If a bell be placed under the receiver of an air-pump, and be kept moving by any mechanical means whilst the air is being exhausted, the sound will grow fainter and fainter, till it ceases entirely as the air becomes highly rarefied. If, on the contrary, the same bell be placed in a receiver, and the air condensed, the sound will become greater in intensity as the air becomes more condensed. For this reason the firing of a cannon on the top of Mont Blanc sounds only like a pistol, whilst the explosion of a pistol is only like that of a pop-gun. When persons ascend in balloons, too, they can hear distinctly the voices of persons far below them, but they are utterly unable to be heard by persons on the earth. Sounds also made in a diving-bell have a painful effect on the ear as compared with the same sounds in the open air. Sounds, therefore, originating at the level of the sea can pass readily into, and be heard on the tops of high mountains; but sounds originating at the tops of mountains, unless of great intensity, will not pass down into the plains below. This fact will give an idea of the immense intensity necessary to cause thunder in the higher regions of the air to be heard on the earth's surface, and also explains the reason why lightning is often seen when no thunder is heard.

It has, till very recently, been taken for granted that all sounds, whether intense or feeble, travelled with the same velocity; and that this is the case in all sounds of ordinary intensity is certainly true; otherwise, a band composed of a great number of different instruments, and giving origin to musical notes of different pitch and intensities, could not be heard at a distance in proper time; but with regard to sounds of great intensity, such as originate in explosions of mines, firing of cannon, &c., where the air is intensely heated, and a kind of accelerating force communicated to the air, it seems probable, from recent experiments, that the greater is the force of the explosion, and the greater is the velocity of the sound.

The waves of sound are reflected from smooth surfaces and cause echoes, which may, according to the distance and form of the reflecting surface, be able only to repeat quick, sharp sounds, or may be able to repeat articulate sounds of several syllables. As sound travels through air at ordinary temperature with a velocity of about 1,120 feet per second, and the ear cannot distinguish sounds as separate if they are repeated oftener than 10 times in a second, it follows that these sounds must be separated by at least 112 feet to be heard separately; and, as in echoes, the sound must travel to and from the reflecting surfaces, the least distance at which an echo can be heard will be 56 feet; but ordinary articulate sounds cannot be heard if they come more rapidly than five or six in a second; so that to repeat an ordinary syllable the reflecting surface must be at a distance of 100 to 112 feet.

The reflection of sound waves from smooth surfaces follow the same laws as those of waves of light. Professor Tyndall beautifully illustrated this by placing a watch in the focus of a parabolic mirror, when its ticking could be distinctly heard by all persons in front of the mirror, and by at the same time showing that all sounds made in front of the mirror could readily be heard at this focus. In the same way, sounds originating in one focus of an ellipse can be readily heard at the other, though quite inaudible in any other part; and sounds uttered between parallel walls, or faces of rock, will be reflected in a series of sounds, following each other rapidly, but with decreasing intensity, just in the same way that the image of objects is multiplied between plane mirrors.

Echoes are sometimes caused by clouds, and are generally most frequent in mountainous districts, so that the mountaineers commonly sing their national songs so that the echoes form to them a natural accompaniment.

Whispering-galleries depend upon the reflection of sound, and also a principle of lateral accumulation, by which, in certain positions of these galleries, the sounds can be heard reflected from any portion of their surface; or else there are two points, so placed that sounds made in one of them can be distinctly heard in the other, though not in any other part.

### QUESTIONS ON CHAPTER X.

1. What is the difference between *noise* and *music*?
2. What are meant by the terms *height*, *length*, *depth* and *amplitude* of sound waves?
3. On what does the velocity of sound depend?
4. Whether does sound pass quicker through *cold* or *hot* air?
5. What is the effect of a large quantity of vapour in the air in reference to sound?
6. What is the distance of a cannon the flash of which is seen five seconds before the report is heard in air of a freezing temperature?
7. What is the velocity of sound in water as compared with its velocity in air?
8. What effect has density on the intensity of sound?
9. Explain the cause of echoes, and under what circumstances they are heard.
10. Explain whispering-galleries.

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## CHAPTER XI.

### Theory of Music: the Gamut, Syren, Monochord. Laws of Vibration of Musical Strings, Pipes, &c.

WHEN isochronous vibrations of sufficient rapidity are excited in any elastic body, these are communicated to the air and surrounding objects, and eventually strike upon the ear, producing what is termed a musical note. A combination of seven of these notes, which have a simple relation to each other with regard to their number of vibrations, is called a diatonic scale; and these notes are distinguished from each other by the letters C D E F G A B. The eighth note, which is formed by twice the number of vibrations of that forming the lowest note, is also called C; and because it is the eighth note above it is called its octave.

If 1 be taken as the length of a string sounding the lower C, then the comparative lengths of another string, in every respect similar, will be as below:

| C | D | E | F | G | A | B | C |
|---|---|---|---|---|---|---|---|
| 1 | $\frac{8}{9}$ | $\frac{4}{5}$ | $\frac{3}{4}$ | $\frac{2}{3}$ | $\frac{3}{5}$ | $\frac{8}{15}$ | $\frac{1}{2}$ |

and their comparative number of vibrations will be as those fractions inverted, as—

| C | D | E | F | G | A | B | C |
|---|---|---|---|---|---|---|---|
| 1 | $\frac{9}{8}$ | $\frac{5}{4}$ | $\frac{4}{3}$ | $\frac{3}{2}$ | $\frac{5}{3}$ | $\frac{15}{8}$ | 2 |

When any two of these are sounded together, the relative vibrations of which are expressed by the lowest numbers, they form what are called chords; the best chords being always between those whose number of vibrations have the simplest solution. Thus, the best of all chords are the octaves, the number of vibrations of which are just double of the other; the next, C and G, the vibrations of which are in proportion of 2 to 3; and the next of C and F, the proportions being 3 to 4. Whilst those between C and D, or C and B, which are represented by large numbers, are called *discords*. There is always a simple relation between the length of the wave and the number of vibrations in a second, for those multiplied together equal the velocity of sound per second in feet. Consequently, the velocity of sound per second, divided by the number of vibrations in a second, will give the length of the wave; and the velocity per second, divided by the length of the wave, will give the number of vibrations.

What is called the pitch of a note, however sounded, always depends upon the number of vibrations in a second; the note having the greatest number of vibrations being said to have the higher pitch. To determine the number of vibrations due to any particular note, two methods are used. The first is called Savart's toothed wheel, and consists of a toothed wheel which is made to revolve rapidly, so that the teeth shall strike against a projecting card. When the wheel revolves slowly, each tap against the card is heard as a distinct sound; but as the rapidity of revolution increases, a musical sound is caused, which rises in pitch with the velocity of revolution.

When this pitch equals that of the note the vibrations of which are to be determined, it is made to revolve uniformly for a few seconds, and then the number of teeth in the wheel, multiplied by the number of revolutions per second, gives the number of vibrations required.

Another instrument for the same purpose, called the Syren, because it produces musical notes in water as well as in air, consists of two disks, with a number of holes in each, equally distant from the centre, and having a stream of air supplied by a pair of bellows, or any other means, so that on causing one of them to revolve when the open holes are opposite each other, the air escapes in puffs; but when the spaces between the holes in the revolving one come opposite to the holes in the other, the air is prevented from passing through, so that a series of puffs of air passing through it, if the disk revolve with sufficient rapidity, throws the air into vibration; and those vibrations equal in number the times which the air is allowed to pass through the holes whilst the disc is revolving one second.

The Monochord is an instrument consisting of a string stretched by weights over a sounding-board, the length of which can be altered at pleasure by a moveable bridge. If this string be stretched with weights, and the moveable bridge so placed that if the bow of a violin be drawn across it it sound the middle C of the piano, and then the bridge be moved till its sound be that of D next above, it will be found that the bridge has been moved $\frac{1}{9}$ of its length, and if then it be further moved till it sound E, it will be found to be shortened by $\frac{1}{5}$, and so of the other notes, till when it sounds the next C an octave higher its length will be exactly one-half.

By means of this monochord and either the toothed wheel of Savart or the Syren, we have easy methods of actually verifying the laws which regulate the vibrations of musical strings. These laws are as follows:—

1st. Strings of the same material and equally stretched have their number of vibrations in the inverse ratio of their length; thus, if one of 8 feet length give a certain number of vibrations, one of 4 feet will give twice, and one of 2 feet four times the number.

2nd. Strings of the same material and length, when equally stretched, have their number of vibrations in the inverse ratio of their diameters. Thus, if a string whose diameter is 1 give a certain number of vibrations, one of diameter 2 would give only half the number, one of diameter ½ twice the number, &c.

This is practically seen in the case of a violin or harp, where the strings sounding the higher notes are much finer than those sounding the lower ones, and, in the case of the harp, both finer and shorter.

3rd. Strings of the same material, length, and diameter, have their number of vibrations directly as the square roots of the weights by which they are stretched. Thus, if one stretched with 1 lb. give a certain number of vibrations in a second, if stretched by one of 4 lbs. it will give twice the number, if by one of 9 lbs. three times, &c.

This is well seen in the case of tightening the screws in the violin, harp, or pianoforte, to raise the pitch of their notes, and it is evident that the greater the tension of the string the greater will be the force to bring it back into a straight line when forcibly pulled out of it, and consequently, just as gravity makes the pendulum oscillate more quickly at the poles than at the equator, so the more tension on the string and the quicker its vibrations. As the number of vibrations of a string is always inversely as its length, and the undulations or wave-lengths in proportion to the length of the string, if of the same thickness, material, and tension, many persons have an idea that the length of the wave generated is always the same as the length of the string. There is, however, no actual connection between these, as may be seen in the violin, where strings of the same length give vibrations entirely different from each other. The length of the wave is *always the distance* sound travels during the complete oscillation of the string on each side of its position of equilibrium, and, as stated previously, may always be found by dividing the velocity of sound per second by the number of their vibrations in the same time.

In the case of tubes and pipes, and indeed of wind instruments generally, the number of vibrations is always in the inverse order of their length; closing one end of a tube or pipe acts in the same way as doubling the length, as the wave must travel the tube in both directions before coming again to the open air.

It is probably owing to the fact that in a tube open at both ends the undulations producing its fundamental note are of the same length as that of the pipe, that many people imagine this is also the case with regard to strings.

### QUESTIONS ON CHAPTER XI.

1. Explain the *diatonic* scale.
2. Which sounds of the octave make the best chords?
3. Explain Savart's apparatus for determining the pitch of notes.
4. Explain the construction of the *syren*.
5. Explain the action of the *monochord*.
6. What is the effect of *thickness* on the sound produced by a string?
7. What is the effect of *tightening* the string of a violin or harp on the pitch of the note it gives out when struck?

## CHAPTER XII.

Light: its Production. Theories respecting Emission Theory. Undulatory Theory: Proofs of its Truth. Sources of Light: Laws of its Decrease. Photometers.

WE now come to those imponderable forms of matter the knowledge of the nature of which, as they elude all our senses and cannot by any known means be weighed or measured, we can only judge of by their *effects*. As to the origin of light itself, two theories, known as the corpuscular or emission theory, and the *undulatory* or wave theory, for a long time were upheld by the most eminent scientific men of the day. The emission theory, to which Newton gave all the weight of his great authority, supposes that light consists of small particles shot out from luminous bodies with extreme velocity, and so small as to pass readily through the physical pores of transparent substances, and thus, passing through the humours of the eye, to strike upon the retina, and by their impact to impart the sensation of vision. The most important objections to this theory are the three following:—

1st. That the velocity of these particles of light is so great that the weight of a single grain would strike the eye with a force as great as that of a cannon-ball weighing 150 lbs., and moving with a velocity of 1,000 feet per second. It seems, therefore, incredible that, however minute these particles are, yet, that falling in such numbers and with such amazing velocity, they should not injure so delicate a membrane as the retina of the eye; and that the impossibility of concentrating by any known means these particles in sufficient abundance to produce the slightest impression on the most sensitive of balances was a pretty certain proof that no such emission of particles had an actual existence.

2nd. According to the emission theory, these particles, on passing into denser media and being refracted, ought to have their velocity augmented, whilst it is well known that, on the contrary, they are retarded just in proportion to the amount of their refraction, passing more slowly through dense media in the exact proportion to which, according to this theory, their velocity should have been accelerated.

3rd. It is known that light, in whatever way it originate, is propagated with the same velocity, and it seems almost incredible that rays should be shot, not only from the sun, fixed stars, and other celestial bodies, but also from meteors, lamps, and candles, with the same velocities, when we know their attractive forces are so different, and that over matter in all its *ordinary forms they* would exert a force differing as *their different* densities. There is, in fact, no more reason to believe that if light consist of particles projected from self-luminous bodies those particles should be projected from so many different sources with the same velocity, than for believing that projectiles should pass through the air with the same velocity, whether shot from a cannon, a rifle, or a pop-gun.

On account of the preceding and other considerations the emission theory was rejected by many eminent men, and received such an overthrow at the hands of Fresnel and Young, that since then the undulatory or wave theory has been accepted as true by nearly all scientific men.

This theory assumes that there exists through all space, and also around the molecules of all bodies, a substance of extreme rarity and elasticity, which has been called, as the agent by which light is propagated, **luminiferous ether.**

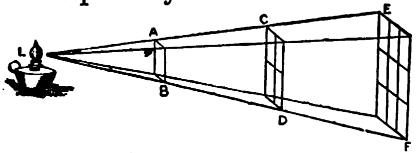
In what has been previously stated with regard to the velocity of sound it has been stated that the velocity through different media depends upon the relation between density and elasticity. In the case of light, the velocity of which is so enormous as compared with sound, the medium transmitting it must be of extreme rarity and elasticity. The ear, as an acoustic instrument, has been stated to have a limited range as regards the pitch of sounds, the limit being generally within ten or eleven octaves, and that, however intense the vibrations of any elastic medium, if the number of these vibrations were less than 16 or more than 8,000 in a second, the generality of ears would be incapable of distinguishing them as sound. With regard to waves of light, however, the range of the eye is very much more limited, being confined to what in music would be considered as one octave; the length of a wave producing the extreme red being about half that of those producing the extreme violet, and the different lengths of the waves producing the different prismatic colours having a close resemblance to those producing the different notes in an octave of music.

But perhaps the strongest proof of the truth of the undulatory theory of light arises from the fact that in every important particular the laws regulating the intensity of sounds, which are evidently caused by undulations of elastic media, are exactly the same as those which regulate the intensity of light, and thus lead us to infer by analogy that they are propagated in a similar way. Thus, the intensities of sound, light, and heat, decrease inversely as the squares of the distance, and increase directly as the squares of the amplitude of the oscillating particles. The undulatory theory, and that alone, also seems to bind the sciences of acoustics, light, and heat, into one harmonious whole, satisfactorily accounting for reflection, refraction, and dispersion, as well as for the colours of thin plates, and that of all other bodies; whilst that of emission breaks down in its explanation of the simplest optical phenomena. It is not, therefore, wonderful that scientific men consider the undulatory theory of light as firmly established as that of almost any law of nature.

But though the undulatory theory of light is thus firmly established, yet many words remain in use which had their origin at the time when the emission theory was generally believed; hence we speak of rays of light, though, according to the wave theory, rays have no physical existence. We also speak of the radiation of light and heat, as if those were thrown off as the radii of a circle from the centre to the circumference, though what we term radiation is simply the communication of motion by a central body to surrounding particles. We also speak of absorption of light and heat, as if the rays projected were absorbed by the body, whilst in reality we mean that the surrounding ether communicates motion to the molecules of the body.

All bodies are either luminous, as the sun, stars, lamps, candles, &c., or they are rendered luminous by the action of luminous bodies, as the moon, trees, houses, and objects in general. Bodies are also considered as *transparent*, as air, water, glass, &c.; *semi-transparent, as* thin plates of mica, &c.; or opaque, as wood, stone, &c. There is, however, no substance known that is thoroughly transparent and which will not absorb some rays in passing through it in proportion to its thickness; and, on the other hand, there is no substance known that, if a layer be taken sufficiently thin, will not allow some rays to pass.

The intensity of light decreases with the square of the distance; thus, if the light emitted by a candle at the distance of 1 foot be considered as a unit, at a distance of 2 feet it will give $\frac{1}{4}$, at 3 feet $\frac{1}{9}$, at 4 feet $\frac{1}{16}$, &c. This law is easily understood if we consider the source of light as occupying the centre of a sphere, its distance from which is in any position equal to the radius, and that, as the surfaces of spheres are always proportionate to the squares of their radii, so the surface over which the light is spread at 1, 2, 3, and 4 feet respectively will be 1, 4, 9, and 16 feet, and that, consequently, the light at any one spot must be as $\frac{1}{4}$, $\frac{1}{9}$, and $\frac{1}{16}$ of what it was at the distance of 1 foot. What is true for the complete surface of a sphere must be equally true for any portion thereof; and if any difficulty be felt in understanding this reasoning it will be easy to take a series of squares of the size of 1, 4, 9, and 16 feet, and, placing a luminous point 1 foot from the first, it will be found to just cover by its shadow the other squares placed at the distances of 2, 3, and 4 feet respectively.



LAW OF INVERSE SQUARES.

This law of the decrease of light with the square of the distance appears to be contradicted by the fact that on a clear evening the lamps and other lights, however distant, seem equal or nearly so in brilliancy; but this apparent contradiction is itself a proof of the truth of the law, for objects appear to us bright or otherwise according to the brilliance of their image painted on the retina; but this brilliancy depends on the size of the image, and *increases* as the size of the image *decreases*; and this reduction in size is also exactly proportionate to the square of the distance; so that the concentration of light on a small space exactly makes up for the decrease of light owing to the increase in distance. This may be proved experimentally by allowing the light from the flame of a candle to pass through a small hole into a darkened room, so that the image of the candle may fall upon a screen placed to receive it. If the candle be placed 1 foot from the hole its image on the screen will occupy a certain space, but if it be removed 2 feet from it the image will only be $\frac{1}{4}$ of its previous size, and if removed 3 feet only $\frac{1}{9}$ of that size, but will remain equally brilliant at such distance.

As we cannot thus judge of the distance of lights by their brightness, we have, in deciding upon the illuminating power of different sources of light, to judge by the darkness of the shadows they cast, as the comparative darkness of the shadows evidently is the difference between the illuminated and non-illuminated surface on which the shadow falls. Instruments for determining the illuminating power of different sources of light are called **photometers**, and generally consist of an upright rod placed before a white screen, on which its shadow is made to fall. If now the two sources of light, the illuminating power of which is to be compared, be placed behind the rod, and a little distance from each other, their shadows will fall near each other upon the screen; and if these shadows be equal in darkness, then the powers of the two sources are equal; but if not alike, then move the one casting the darker shadow farther distant, till the two shadows are equal, and then, by squaring their respective distances from the rod, their separate powers of illumination will be known. Thus, if one be at 4, and the other at 6 feet distance from the rod when this equality of shadow takes place, then their illuminating powers will be as 16 to 36.

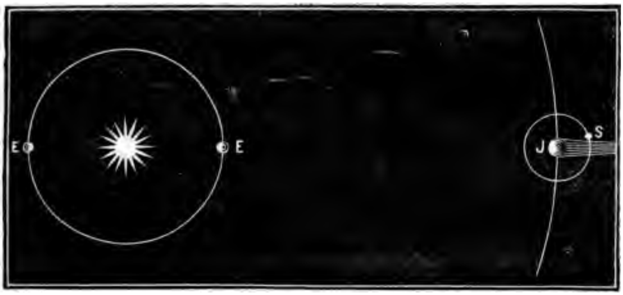
### QUESTIONS ON CHAPTER XII.

1. State the *emission* theory of the origin of light as held by Newton.
2. State the three principal objections to this theory.
3. Who were principally instrumental in establishing the undulatory theory?
4. State the connection between the propagation of light and that of sound.
5. State the difference between *luminous* and *non-luminous* bodies.
6. How do the intensities of heat and light decrease with distance?
7. How is this law apparently contradicted by looking on lamps, &c., on a clear evening?
8. Describe the methods used to determine the intensities of different lights.

## CHAPTER XIII.

Velocity of Light: how Discovered. Foucault and Bradley's Calculations thereof. Reflection of Light. Different kinds of Mirrors. Refraction by different Media. Total Reflection, and the Phenomena depending thereon.

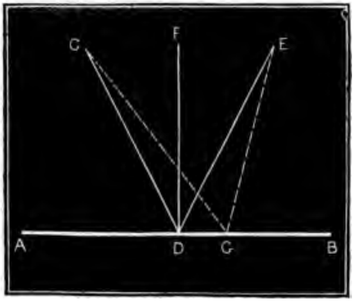
THE passage of light from one place on the earth's surface to another appears instantaneous, yet that it takes an appreciable time to travel through great distances was proved by Olof Roemer, a Danish astronomer, nearly 200 years ago. He had calculated accurately the time of revolution of one of Jupiter's satellites, and found it exactly 42 hours 28 minutes and 35 seconds. He had determined this at a time when the earth in its orbit was nearly in a line between the sun and Jupiter; but as the earth gradually passed in its orbit farther from Jupiter, he found that the planet emerged from behind Jupiter gradually later and later, till on its hundredth appearance, when the earth was nearly on the opposite side of the sun to Jupiter, its appearance was so far retarded as to be *fully 15 minutes* behind its calculated time. By a *happy kind* of inspiration, he considered that light took this 15 minutes to travel the greater distance, and making allowance for the difference between the nearest and most distant part of the earth's orbit from Jupiter, he calculated that light took 8′ 13″ to travel from the sun to the earth, and thus calculated its velocity as 192,500 miles per second. This, however, was based on the erroneous assumption that the earth was 95,000,000 of miles from the sun, and that thus the difference between the nearest and the most distant position of the earth to Jupiter was 190,000,000 of miles. It is now, however, known that this difference is only 183,000,000 of miles, and the velocity of light, therefore, instead of being 192,500, is only really a little more than 185,500 miles per second; and this agrees with the more recent and accurate experiments of M. Foucault, who, by means of rotating mirrors, determined the velocity of light in air at 185,157 miles per second; and since we know that light is retarded in passing through dense media proportionately to the angle of refraction, it may be easily demonstrated that a velocity of 185,500 miles in ether will correspond, as accurately as experiments of this kind can determine, with a velocity of 185,157 miles in air.



VELOCITY OF LIGHT.

The velocity of light was also determined independently by Bradley, in 1723, from the aberration of *light, and the* place where he made the discovery is *still marked* by a dial in Kew Gardens. His calculation agreed very nearly with that of the Danish astronomer; but as it depends upon the velocity of the earth in its orbit, and that is now known not to be so great as it was believed to be at that time, when allowance is made for this, the velocity of light as thus determined is very nearly the same as that resulting from the experiments of M. Foucault.

**Reflection of Light.**—Whenever a wave of light passes from one medium to another, or strikes upon any surface, a portion of it is always turned back or reflected. If the surface on which it falls be smooth and even, it is regularly reflected; but if the surface be rough and irregular, then the light reflected is scattered in all directions. From the surface of all bodies white light is reflected, but many bodies reflect a portion from their outer surface, and a portion partly passes into the body, and is then reflected. It is from this internal reflection of coloured rays that bodies owe their colour, as they are only visible by the rays they reflect. To prove this, take a number of brilliantly coloured flowers or ribbons into a darkened room, and illuminate them by light of any one colour; they will then all appear either entirely black or of the colour of the light which falls upon them.



REFLECTION OF LIGHT.

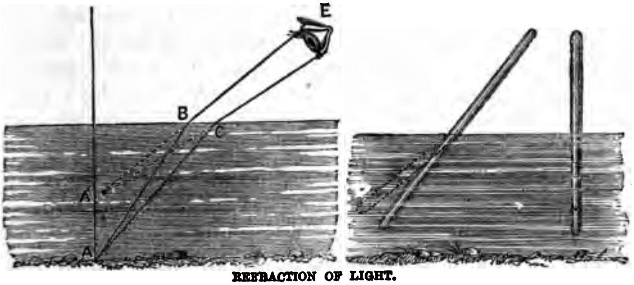
If the surface on which light falls have a great number of polished faces, as in ordinary multiplying-glasses, then as many images will be formed by reflection as there are smooth faces; but if the surface be roughened, as in frosting glass, then though light will pass through or be reflected *from the surface,* no image is formed by reflection, *and no object* can be clearly distinguished through glass so treated. If light fall perpendicularly upon any smooth surface, it is reflected back upon the same straight line; but if it make any angle with the perpendicular, it will be reflected just at the same angle on the opposite side. This is expressed by saying that the angle of incidence always equals the angle of reflection. This law has been accurately verified by the most rigid analysis, but it may be easily illustrated by having two moveable tubes that can be arranged to make different angles perpendicular to an ordinary mirror; on adjusting the tubes to make any equal angle with the perpendicular, and placing a source of light at the end of one tube, and the eye at the other, the image of the source of light will be reflected to the eye, but if these angles are unequal it will not be seen. Hence if they each make an angle of 30°, 40°, or 50°, the image will be clearly seen by reflection; but if one make 30°, and the other 40°, or, in fact, any other than 30°, it will no longer be visible.

All images formed by mirrors depend on this law of reflection, which is true whether the mirror have a plane, convex, or concave surface, It is also equally true whether the mirror be made of polished metal or of glass, the back of which is coated with metal; only in the latter case there will be two images formed, whenever the incidence is oblique; one from the anterior surface of the glass, and the other from the metallic coating at the back. If the incidence be very oblique, a number of these images can be seen, especially if the glass be thick; these images are formed by the mutual reflections between the metal behind and the front of the glass, those from the metallic surface being much the brighter, on account of metal reflecting better than glass. These images may be well seen by placing a candle a few inches from the end of a plane mirror, and the eye an equal distance from the opposite end, when a long line of these reflected images will be seen growing gradually fainter, till they quite disappear. If *two plane mirrors are placed* with their faces parallel, and *about a foot apart*, a person looking between them at one end will see also a number of these reflected images, which will seem fainter and fainter till they entirely disappear. In plane mirrors the images formed by reflection are always the same size as the object, upright in position, but inverted laterally, *i. e.*, the left side appearing as the right, and the right as the left; and in position they always appear as far behind the mirror as the object is in front. In convex mirrors the images are always erect, and smaller in size than the object. In concave mirrors they are generally inverted and smaller; but if the object be placed very near the mirror, then the image is erect and very much magnified.

**Refraction.**—When a wave of light passes from one transparent medium into another part of it, it is always transmitted; but unless it fall upon it perpendicularly it never proceeds in the same straight line, but always appears broken at the surface, and is bent either to or from the perpendicular, according to the nature of the two media from and into which it is passing. Generally, in passing from a rare into a dense medium, the ray is bent towards the perpendicular; and in passing from a dense into a rare medium, it is bent from the perpendicular. Hence, in passing from the ether that pervades space into air which is gradually more and more dense, it is bent more and more towards the perpendicular, and this causes the sun, moon, stars, &c., to appear to us higher than they really are, and causes also the sun and moon, when near the horizon, to have somewhat of an elliptical or oval shape. On this account, also, we actually see them before they are really above the horizon, and after they are below it. Whatever the angle made by an incident ray upon any surface, and however much it may be bent out of the direct line, the line of the angle of incidence, divided by the line of the angle of refraction, is always a constant quantity, and this constant quantity is called the index of refraction, and is always the same for the same substances. This index, in passing from ether into water, is 1·3; and for passing into glass, 1·5; into phosphorus, 2·24; into diamond, nearly 2·5; and into chromate of lead, the index of refraction of which is the greatest known, nearly 3.

It has been previously stated that light travels slowest through substances whose index of refraction is greatest; and it is equally true that transparent substances, whose index of refraction is greatest, transmit the smallest, and reflect the greatest quantity of oblique rays falling upon them. It is on this account that glass reflects more and transmits fewer rays than water, and that the diamond reflects nearly the whole of the light falling upon it, and thus appears of such dazzling brilliancy.

As we, on account of refraction, see the heavenly bodies higher than they really are, so we also, on looking downwards into water, see the bottom of pools, lakes, rivers, &c., higher than they really are; and if we place a pencil or straight rod of any kind obliquely into water, it appears broken where it enters the water, and as if it were bent upwards. The more obliquely it is inserted in the water, the more it appears to be bent; and if a vessel of any kind—as a saucer or shallow basin—be quite filled with water and the eye be placed on a level with it, the bottom of the vessel will appear to float at the top of the water; and if a penny or a shilling be placed at the bottom of a basin quite full of water, an eye at a distance at the same level as the basin will see the penny, or shilling, as if it floated on the top of the water, in all cases where the angle formed by them between the edge of the vessel and the horizon



REFRACTION OF LIGHT.

is less than 42½°. In fact, the bottom of any vessel filled with clear water can always be seen by an eye placed on a level with the top, and at some distance if the width of the vessel is greater than its depth in the proportion of 50 to 40. To understand this it is only necessary to bear in mind that, as all rays in passing from water into air are bent downwards, and from the perpendicular to the surface, and as objects always appear to be in the direction of the rays that come from them to the eye—so rays passing from water into air, as they become more and more oblique, will be bent down lower and lower till they will in the end glide along the surface, and any object from which those rays come will appear to an observer whose eye is level with that surface to be floating on the top of the water. The angle these rays, which just glide along the surface in air, make with the perpendicular in water is 48½°. It is equally true that any ray of light just grazing the water, or making an angle of nearly 90° with the perpendicular, will be bent on entering the water till it makes, with the perpendicular, an angle of 48½°. To prove this experimentally, place a source of light in a room otherwise dark on a level, or just above the level, of a cubical vessel, and at some distance from it, so that the shadow of the side of the vessel nearest the source of light comes nearly to the top of the opposite side, leaving the inside of the vessel in shadow; then gradually fill the vessel with water, and when it is quite filled the shadow will fall back, leaving nearly half the vessel illuminated; and if the angle made by the shadow and the side of the vessel be accurately measured it will be found to be 48½°.

It is evident, therefore, that no ray making with a perpendicular an angle of more than 48½° can pass from water into air, and therefore that is called the limiting angle of emergence. This limiting angle for glass is about 39°, and for diamond, less than 24°. What, then, becomes of those rays that cannot emerge from water into air? They are reflected back again; and, as they are all reflected even more perfectly than rays incident on the most polished metallic mirror, they are said to be *totally reflected*, and this phenomenon is called *total reflection.* A fish, or any other animal, in still water, therefore, instead of seeing everything above the horizon in an angle of 180°, will see them all crowded into a space of 97°, or occupying only a little more than half their natural position; and beyond this angle they will see the bottom of the water totally reflected, and that with greater clearness than it could be reflected from a mirror. This will, of course, enable them to see anything directly above them in its true position, but all objects near the horizon very much distorted and contracted in altitude, so that trees, men, &c., on the banks will not appear of half their true height.

**Total Reflection** enables us to account for many atmospheric phenomena, especially what is called mirage of the desert. In the desert, the sun's rays being reflected from the hot sands, the air near the surface of the earth is less dense than the upper layers, and rays of light falling upon them from distant objects are bent more and more from the perpendicular, and at length come to a layer which they cannot penetrate, and become totally reflected, as if from the surface of water, till they strike the eye of the weary traveller, who, seeing them thus reflected, cannot help thinking it is actual water that he sees before him. It is also by a series of unequal refractions and total reflection that the phantom ship, the spectre of the Brocken, and other kindred phenomena are easily accounted for.

### QUESTIONS ON CHAPTER XIII.

1. Describe the discovery of *Olof Roemer* with regard to the velocity of light.
2. Mention the calculations of Foucault and Bradley on the velocity of light.
3. Why were Roemer's and Bradley's calculations erroneous?
4. What effect has the reflection of light on the colour of bodies, and how can you prove it?
5. On what does the formation of images by mirrors depend?
6. What are multiplying glasses?
7. How can you arrange the light so that an ordinary glass mirror will give a series of images?

8. What is meant by the index of refraction?
9. What effect has refraction on the appearance of the heavenly bodies?
10. Explain the phenomena arising from *total reflection.*

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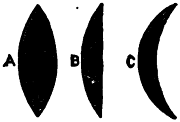
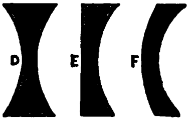
## CHAPTER XIV.

Lenses: different Kinds of: Images formed by them: Size of Image, Microscopes, Telescopes, &c. The Eye, Description of: Adjustment of, for Different Distances. Long and Short Sight, Blind and Yellow Spot, &c.

Having now treated of reflection and refraction, we can better understand the use of lenses. These are made of some transparent and refracting substance bounded wholly, or partially, by curved surfaces. They are made mostly of glass, and are used to make rays of light passing through them either converge or diverge more than they did on entering them. The former kind have always one or more of their faces convex, and the latter always one or more concave. Parallel rays passing through a converging lens will be brought together at some point on the opposite side which is called the principal focus. Divergent rays passing through a converging lens, if they come from a point more distant than its principal focus, will also be brought to a focus, but at a distance greater than that of parallel rays; but converging rays passing through such a lens will be brought to a focus at a point nearer the lens than the focus for parallel rays. If an image *of sensible* magnitude be placed outside the principal *focus of a* converging mirror, an inverted image will



CONVERGING.

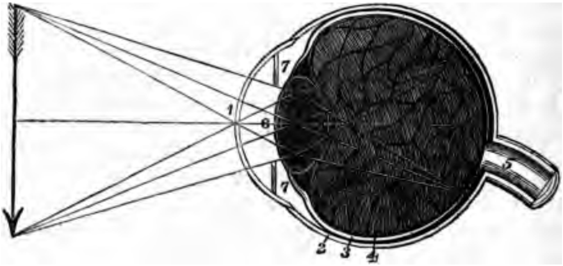


DIVERGING.

be formed on the opposite side. This image may be greater or less than the object, according to its distance from the focus, but in every case the image and object are convertible, so that if an object—say of 4 feet in area—form on the opposite side of the mirror an image of 2 feet in area, if an object 2 feet in area were substituted for the image, it would form an image on the other side of 4 feet in area, which would occupy the same position as the original object. It is on the practical application of this principle, indeed, that all optical instruments depend for their utility. In microscopes, which are used to examine small objects, these objects are so placed that they form images much larger than themselves; and in compound microscopes these images are again magnified still further by a second lens called an eye glass. It is also in this way that magic lanterns form from small objects large images, which are formed on a screen placed at a proper distance to receive them, and where they can be seen by the spectators. Telescopes, on the contrary, are generally arranged so that they form a small image, the distinctness and clearness of which is very little inferior to that of the object, and this image is then magnified by being examined through another lens.

The eye is for light what the ear is for sound, and it is by its means only that all the impressions made by the waves of light can be communicated to the brain. It has been previously stated that if the rays of light from any object pass through a small opening into a darkened room and be received upon a screen properly placed, an inverted image of the object from which the rays come will be painted on the screen. Such an arrangement, with a converging lens placed in the aperture, is called a camera obscura. It will be evident, however, that to secure a proper image the object and the screen must be placed at a suitable distance, and that if the object be brought nearer the screen must be moved farther away, or a lens of greater curvature used which will bring the image nearer.

If, *on the contrary*, the object be placed at a greater *distance, then* the screen must be brought nearer, or a lens of less curvature used, or the image will fall short of the screen. Now the eye as an instrument of vision very much resembles the camera, but excels it in its power of adjustment. In front of the eye is the cornea, a firm transparent lens fixed into the sclerotic coat of the eye, something in the same way as a watch glass. This cornea has a greater curvature than the rest of the eye, and causes it in front to bulge out. The cornea is a converging lens, but of itself would not converge the rays falling upon it sufficiently to form the image on the retina. Inside the cornea is the aqueous humour, and separating this from the vitreous humour which fills the principal cavity of the eye is the crystalline lens, which is fixed firmly by ligaments to the choroid and sclerotic coats, near the place of insertion of the cornea. The back of this lens can be flattened or made more convex by the action of muscles, by which it is attached; it being flatter when these muscles are relaxed, and more rounded when they contract. In front of this lens is suspended a curtain, the iris, having in its centre an opening termed the pupil. This opening contracts under the stimulus of a strong light, and enlarges when the light is feeble, so that to a certain extent it regulates the quantity of light admitted into the chamber of the eye. The inside of the chamber of the eye is lined with a dark pigment which absorbs the light, and over this is spread a thi



THE EYE.

and very complicated network of connective tissue and nerve fibre, called the retina, on which the image must be formed for its impression to be communicated to the brain.

The rays from all objects that fall upon the eye are divergent, this divergence increasing as the object comes nearer to the eye; but, as has been previously stated, the more divergent the rays the more distant from the lens will the image be formed, unless the curvature of the lens can be increased so as to make up for the increased nearness of the object and consequent divergence of the rays. If two objects, such as a shilling and a farthing, be placed one at 6 inches, the other at 10 or 12 inches from the eye, it will be found that they cannot be both seen distinctly at the same time; if the nearest be distinctly seen, the farther one will be seen imperfectly, and if the more distant one be seen distinctly, then the nearer one will be seen imperfectly. The eye can, in fact, be adjusted to see either perfectly, but the perfect image of both cannot be formed on the retina at the same time; and were the eye incapable of adjusting itself to different distances, it would be impossible to see objects distinctly, unless they were placed at the particular distance to which the eye was adapted. The process of adjustment to difference of distances consists, then, in drawing the choroid coat forward by muscular action, and thus giving a more rounded form to the back part of the crystalline lens, when it is necessary to look at near objects.

When, however, as is frequently the case in youth, persons have the cornea or the crystalline lens so rounded, that they converge the rays from objects placed at an ordinary distance so much, that their images fall short of and are formed in front of the retina; then, in order to throw the image upon the retina, so that they may be distinctly seen, it is necessary for them to bring the objects very near the eye, so that the increased divergence of the rays may make up for the excess of curvature in the cornea or *crystalline lens.* Such persons are said to be *near* or *short-sighted,* and in order that they may see distinctly at ordinary distances, they require spectacles or lenses, with at least one concave surface, so that the rays passing through them may be made more divergent. On the other hand, in old age the cornea and lens frequently become flattened, so that the rays from objects at an ordinary distance form an image behind the retina. To partly remedy this, persons so affected naturally place objects, such as books, &c., which they wish to see distinctly, at a distance, and are said to be long-sighted; but that they may see objects distinctly at ordinary distances, they require spectacles with converging lenses, so that the image may fall upon the retina; and as this flattening generally increases with age, they require lenses more and more convex as they advance in years.

Though the retina as a whole is generally spoken of as the medium by which the impression of light is communicated to the brain, yet the probability is that it is only a very small portion of the retina, viz., the layer of rods and cones that has in reality the power of translating the waves of ether impinging upon it into light.

It is known that the place where the mass of nerve fibre forming the retina passes into the eye is utterly blind, and if the image of any object be thrown upon it, no impression thereof is communicated to the brain; whilst, on the contrary, what is known as the yellow spot directly opposite the pupil, is the place where the most distinct images are formed; and this part of the retina is formed almost entirely of rods and cones.

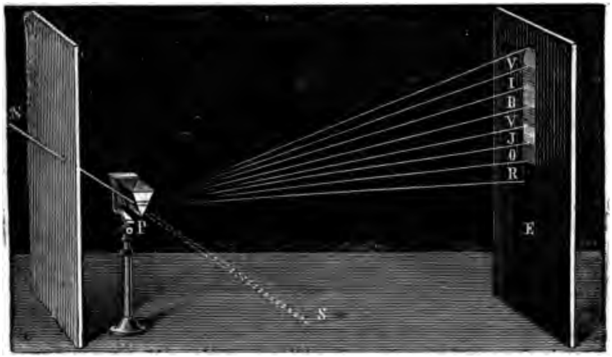
### QUESTIONS ON CHAPTER XIV.

1. Mention different kinds of lenses.
2. What is the principal focus of a lens?
3. Describe the *camera obscura*.
4. Describe the different parts of the eye.
5. What regulates the quantity of light admitted to the eye?
6. How can the eye be adjusted to different distances?
7. What is the effect of too great roundness of the cornea, or crystalline lens?
8. What of their being too flat?
9. What is meant by the blind spot?
10. Where are the rods and cones in greatest number?

## CHAPTER XV.

**Prisms: their action on Light. Solar Spectrum. Rays of Light, Heat, and Chemical Activity. Rainbow. Complementary Colours.**

It has been stated previously that if light pass obliquely through a plate of glass, or any other refracting medium, when it passes again into the air it is bent as much from the perpendicular as it was bent towards it in passing through the glass, so that it passes in the same direction as before it entered the plate; but it will not really be in the same line, though parallel to it, and will be moved out of that line in proportion to its obliquity of incidence and the thickness of the plates. If, however, light pass through a wedge-shaped plate, whose edges are not parallel, then the ray will not only not pass in the same direction, but it will be separated into different parts, or dispersed, forming a line of coloured rays, called the solar spectrum. Light, then, instead of being homogeneous, is found to be composed of different coloured rays, some of which are bent more and others less in passing through the glass; those bent most out of a straight line being the violet, those bent least the red.



DISPERSION OF LIGHT.

They appear, therefore, in this order—violet, indigo blue, green, yellow, orange, and red.

It was proved originally by Newton, and has since been abundantly confirmed, that the waves producing those different colours are of different lengths, those producing the violet being $\frac{1}{576000}$, and those producing the red about $\frac{1}{390000}$ of an inch in length; and as the shorter waves are more retarded in passing through the glass than the long ones, so they are bent more out of the straight line.

Colour, then, is to light what pitch is to sound, the extreme red corresponding to the gravest, and the extreme violet to the highest musical note. It is, however, found that though the waves of ether producing light are all included between the extreme red and the extreme violet, yet there are beyond the violet rays quicker and shorter, which, though they cannot produce light, yet produce chemical action, whilst there are beyond the red slower and longer rays, which, though incapable of producing light, produce heat to a greater extent than the waves producing light. On account of the different length of the waves of heat, light, and chemical activity, it is possible to separate them and to bring them each separately to a focus. By thus concentrating the heat rays to a focus entirely destitute of light, heat enough can be obtained to fuse metals, burn combustible substances, and thus to convert the non-luminous into luminous rays, by giving to them a quicker motion. On the other hand, the rays beyond the violet, if made to fall on certain substances, will produce a chemical action that throws the waves into longer periods, and thus causes them also to appear as light. On sounding any particular note in a room where there are several musical instruments, the air will be thrown into vibration, and this vibration will communicate itself to all those parts of the different instruments capable of sounding the same note. If the vibration be powerful enough, they may also excite all the octaves and harmonics; but no matter how powerful the vibrations, they will produce no effect on those parts of the instrument with which they are not in harmony. It is thus with the waves of light, they strike upon all kinds of objects, passing through some, and being reflected back from others; whilst in the interstices of most they are resolved as by a prism into their separate colours, where the waves of some colours are destroyed and others blend together, and either reflected or transmitted gives us all the varying hues that are seen in the world around us. Thus some bodies destroy the long slow wave of red, and blend together the yellow and blue into all the lovely shades of green on which the eye loves to rest when wearied of more gaudy colours. Others, again, as the flowers of the crocus and daffodil, destroy not only the long waves of red, but also the quicker and shorter ones of every shade of blue; whilst again others destroy red and yellow alike, and reflect only the short quick waves which give every shade of blue. Others again destroy or absorb entirely waves of every length, and appear black; whilst if they only destroy them partially they appear as sober grey. White light is reflected more or less from the surface of all bodies, of whatever colour, but if they also reflect without destroying any colour internally, then they appear white, and if they are transparent with a large index of refraction, as the diamond, then the great quantity of white light they reflect from their polished surfaces gives to them their brilliancy.

The rainbow, which can only be seen when the sunlight falls on descending rain, is caused by the drops of rain acting as so many prisms, and separating the light falling upon them into their separate colours. A ray of sunlight falling on a drop of rain is refracted at its outer surface on entering, and then, partly reflected from its inner surface, is again refracted on leaving the drop; and, just as in the case of the prism, this refraction being unequal for different coloured rays, they are separated, and form a kind of solar spectrum. On account, however, of most of these rays being divergent, they do not reach the eye; but at an angle varying, according to the refrangibility of the rays, from $40\frac{1}{2}°$ to $42\frac{1}{2}°$ with a line drawn from the sun through the eye of the spectator and produced onwards, they will issue from the drop parallel; those at an angle of 42½° sending to the eye rays of red, those at 40½° rays of violet, and between those two the other colours will appear in the same order as in the solar spectrum. This is the primary bow, and it is evident that when the sun is near the horizon, nearly half the circumference of the bow will be seen, as then the line between the sun and the eye of the spectator, which forms the centre of the bow, will also be near the horizon; but the higher the sun is in the heavens, the smaller is the part of the bow which can be seen, as then the line joining the eye of the spectator and the sun will, when produced, be proportionately below the horizon.

In addition to the primary bow, a secondary one, much weaker in its colours, is frequently seen, broader and higher than the primary bow, and having its colours in a reverse order; thus, the red is highest, and forms the outer portion of the primary bow; but in the secondary the violet rays form the outer, and the red the inner circle of the bow, the red of the primary and that of the secondary being nearest together, and the violet of each the farthest apart. This secondary bow is formed by rays which have struck the lower surface of the drop, and have been twice reflected, as well as twice refracted; and it is this secondary reflection which makes the colours of the secondary bow so much less distinct than those of the primary one.

Whilst the width of the primary bow is generally only about 2°, the width of the secondary is about 3½°, and the distance between them is about 4°.

Though there are seven prismatic colours, yet they are really all derived from three primary colours, viz., red, blue, and yellow. The violet and indigo being only different shades of blue with a slight mingling of red, the green being a mixture of yellow and blue, and the orange one of red and yellow. Each one of these has what is called its complementary colour, that being the one into the composition of which it does not itself enter. Thus the complementary colour of red is green, as green is made of a mixture of the yellow and blue; again, the complementary colour of blue is orange, the orange being made up of red and yellow, but containing no blue. The retina becomes wearied by dwelling on any bright colour, and has its sensibility for that colour for a time destroyed; hence, if you look fixedly for a short time on a red wafer, and then on anything white, a green spot will appear of the size of the red wafer; and in all cases the complementary colour will appear to the one on which the eye has rested. The same thing will occur if, after looking at any bright colour the eye be closed completely; the eye will then appear to see the complementary colour to that on which it had rested before it was closed. Just as the retina wearied with any bright colour produces the complementary one when it is withdrawn, so, in ordinary cases, it retains any impression made upon it for a sensible time; so that if two impressions be made upon it following each other rapidly, they will appear as one; and if a series follow with sufficient rapidity, they will all blend together. Hence, if a lighted torch be rapidly whirled round, it will form a complete ring of light; and the spokes of a rapidly-revolving wheel all blend into a shadowy complete circle. If a disc, on which are painted in proper proportions either the seven prismatic colours, or simply red, blue, and yellow, be rapidly revolved, these colours will, in this way, be blended together, and appear as white.

### QUESTIONS ON CHAPTER XV.

1. What is the action of a prism on light?
2. Which rays are most, and which least refracted?
3. How can we discover the invisible heat rays?
4. What is the similarity between light and sound?
5. How are the colours of plants produced?
6. What kind of light is reflected from the surface of all bodies?
7. When do we see the rainbow?
8. What part of the day is the rainbow largest?
9. How are complementary colours made to appear after the eye is closed?
10. *How can* we blend seven different colours so as to make them *appear white?*

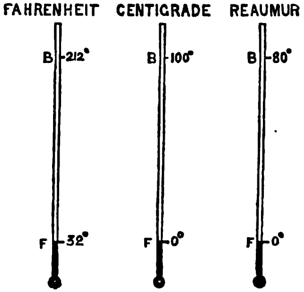
## CHAPTER XVI.

**Heat: Methods of Producing. Measurement of Heat. Centigrade, Fahrenheit's and Reaumur's Thermometers. Expansion of Solids. Compensation Pendulums: Harrison's, Graham's. Effects of Unequal Expansion.**

There is now little doubt but heat, as well as light, is caused by the vibrations of ether. Many of these vibrations giving both heat and light; but others, whose undulations are too slow to produce light, producing only heat. There have, with regard to heat, as with regard to light, been two theories. One supposing that heat, or caloric, was a substance that could be communicated from one body to another; consequently, that the addition of this substance made bodies hotter in proportion to the amount of it imparted to them; whilst its loss by any means reduced their temperature, and made them colder. Another, that all heat is motion, and that, in fact, motion and heat are convertible into each other; all motion causing heat, and all heat being the effect of motion. According to this theory, therefore, the more motion is imparted to a body, the more heat it contains; whilst the loss of this motion reduces its temperature.

Of the exact amount of heat contained in any body we are not, however, able to judge simply by the sensations they produce. To illustrate this practically, take three basons; one filled with hot water, another with cold, and the third placed in the middle, of a temperature the mean of the two. Place then one hand in the hot and the other in the cold water for a short time, and then withdraw them and place both in the middle one, when the water therein will appear cold to the hand taken out of the hot water, and warm to the one taken out of the cold. Take again, as another example, Quito, which is a city under the equator, at an elevation of about 8,000 feet above the level of the sea, and possessing a genial and temperate climate all the year round. Beautiful and genial, however, as the climate of Quito is to its regular residents, persons who come to it from the hot plains below generally complain of it as being too cold; whilst others, who visit it from the mountains above, complain of it as being too hot.

It is therefore necessary for determining the exact temperature, that some instrument more uniform in its indications than our senses should be used. Instruments for determining ordinary temperatures are called thermometers, or measurers of heat; and consist nearly always of a glass bulb with a small tube, in which the liquid in the bulb may expand. The liquids placed in them are nearly always alcohol, for very low temperatures, as it never freezes; and for other temperatures, mercury. As liquids within ordinary limits expand equally for equal amounts of heat, the tubes are graduated by first plunging them into water containing ice, and marking that point as the freezing; and then placing them into boiling water, marking this as the boiling point. There are three differently divided scales in use. First, that of Celsius, called the Centigrade thermometer, used chiefly on the Continent, and partly in England; the freezing point is called the zero, and the boiling point is marked 100°; and these divisions are continued above and below, any point below freezing being distinguished by a negative sign, as – 1°, – 2°, &c. The second, that of Fahrenheit, in which the space between the freezing and boiling points is divided into 180°. He, however, began to graduate it, not at the freezing point, but at a point 32° below it. This point he obtained by placing the bulb in a mixture of snow and salt, and marking this as the zero point, believing it to be the lowest temperature attainable. The third is that of Réaumur, who divided the space between the freezing and boiling points of water into 80°, and graduating in other respects the same as that of the centigrade; 4 of his divisions corresponding to 5 in the Centigrade, and to 9 of Fahrenheit. In all these thermometers 80° Réaumur, 100° Centigrade, and 212° Fahrenheit, respectively represent the temperature of boiling; whilst the zero of Réaumur and Celsius, and 32° Fahrenheit, each respectively represent the temperature at which water freezes.



THERMOMETERS.

To convert degrees of Réaumur into Centigrade, it is only necessary to multiply by 5 and divide by 4; and to multiply by 4 and divide by 5, in order to change Centigrade to Réaumur. To change Fahrenheit to Centigrade, it is necessary first to subtract 32°, as that will give the point corresponding to the zero of each of the others; then to multiply the remainder by 5, and divide by 9, to bring them into Centigrade, or by 4 and divide by 9, to bring them to Réaumur. To change Centigrade to Fahrenheit, multiply by 5 and divide by 9, and add 32° to the quotient.

**Expansion.**—Heat expands all bodies by increasing the repulsive force of the molecules, and thus separating them farther from each other. Expansion is spoken of as *linear*, *superficial*, and *cubical*.

This expansion is least for solids of all kinds, greater for fluids, and greatest of all for gases. It is, however, very different for different kinds of solids; thus, in passing from 0° to 100° Centigrade, or from 32° to 212° Fahrenheit—

| | | | |
|---|---|---|---|
| Lead and Zinc | expand nearly | $\frac{1}{300}$th | of their length. |
| *Silver and Tin* | ,, | $\frac{1}{500}$th | ,, |
| *Copper and Brass* | ,, | $\frac{1}{600}$th | ,, |
| *Gold* | ,, | $\frac{1}{700}$th | ,, |

Iron and tempered Steel } expand nearly $\frac{1}{800}$th of their length.
Platinum and Glass „ $\frac{1}{1200}$th „

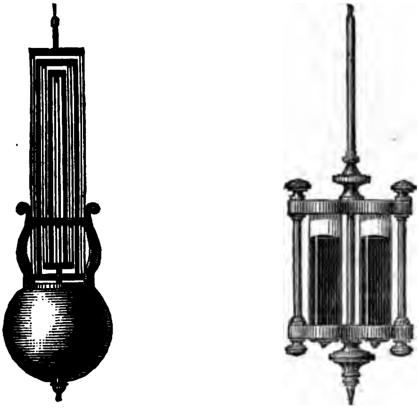
So that for the same amount of heat, lead and zinc expand four times, and copper and brass twice as much as platinum and glass. Metals whose coefficients of expansion are nearly equal, may be combined together in any way without danger of fracture by change of temperature, whilst those whose coefficients of expansion are very different, cannot be combined without danger of their breaking away from each other on any great or sudden change of temperature. Platinum may thus be soldered into glass, and they will expand together without fracture; but if copper or silver be soldered into glass in a similar way, any sudden or great change of temperature will fracture the glass, owing to the greater expansion of the metal.

With regard to solids, the fraction of their length that they expand in passing from the freezing to the boiling point of water is called their coefficient of expansion. Thus, if a bar of metal 20 inches long, lengthened to $20\frac{1}{2}$ inches for this change of temperature, its coefficient for linear expansion would be $\frac{1}{40}$, as it would increase its length by that fraction; but if this bar were 5 inches wide, and it expanded equally in all directions, it would evidently not only be $\frac{1}{2}$ an inch longer but $\frac{1}{8}$th of an inch wider, and its superficial arc, instead of being $20 \times 5$, or 100, would be $20\frac{1}{2} \times 5\frac{1}{8}$, or $\frac{41}{2} \times \frac{41}{8} = \frac{105}{16}$, or $105\frac{1}{16}$, which is a little more than twice $\frac{1}{40}$ of 100. But, again, if the same bar were 2 inches thick, it is evident that it would expand also in thickness by twice $\frac{1}{40}$, or $\frac{1}{20}$, and therefore its cubical contents would be represented by $20\frac{1}{2} \times 5\frac{1}{8} \times 2\frac{1}{20}$, instead of $20 \times 5 \times 2$, as before the expansion took place. It is evident, therefore, that, to calculate accurately, the cubical expansion is a somewhat complicated affair; but where the coefficient of expansion is small, it is sufficient to reckon the coefficient of superficial expansion *as twice the* linear. Thus, in the case mentioned, *taking twice* $\frac{1}{40}$, or $\frac{1}{20}$, and multiplying $21 \times 5$

$= 105$, which is very nearly accurate, and similarly taking 3 times $\frac{1}{40}$ for the cubical expansion, and taking $21\frac{1}{2} \times 5 \times 2$ for the cubical contents after expansion would differ very little from the true result. Practically, therefore, whatever be the coefficient for linear expansion, twice that is reckoned for the superficial, and three times that for the cubical, or its expansion in all directions.

Though all bodies expand by heat, yet they expand very unequally. Take, as an illustration, the case of the thermometer itself, and suppose that the glass tube and the mercury, or alcohol, it contains expand equally, there would in that case be no rise of the mercury or alcohol; for as the bulb and tube expanded equally they would just occupy the same space in it at all temperatures; but because the mercury and alcohol expand much more than the glass, that increased expansion causes them to rise in the tube. In reality any sudden increase of temperature causes the mercury in the ordinary thermometer FIRST to fall; for as the glass is exposed to the increased temperature, and is not a good conductor, it expands first, causing the mercury to fall slightly in the tube; so soon, however, as the heat penetrates the glass fully, and communicates the increased temperature to the mercury, it begins to expand rapidly and rises, owing to its expansion for the same amount of temperature being much greater than that of the glass.

As all bodies expand with heat, and it has been previously stated that a pendulum beats slower as it is lengthened, and quicker as it is shortened, it is evident that a clock regulated by a pendulum will move slower if the metal of which it is formed lengthen, and quicker if it contract. Clocks thus regulated, then, would move slower in summer than in winter; and when used in vessels traversing hot and cold climates, would go slower in hot than in cold. By making, however, a compound pendulum of different metals, and so arranging them *that one of* the metals by expanding upwards tends to *shorten the* pendulum as much as the other, expanding *downwards*, tends to lengthen it, they may be so constructed as to remain of the same length at any temperature. It was not, however, until a large amount had been offered by the Government to any person who should invent any means of overcoming the difficulty of regulating the movements of chronometers exposed to great changes of temperature that this method was discovered. The first and most noted of these was invented by Mr. Harrison, and is known, from its shape, as the "gridiron pendulum." In this the elongation of the steel bars downwards is compensated by the elongation of shorter bars of copper upwards, so that the bob of the pendulum remains equally distant from its point of suspension at all temperatures. Perhaps the simplest and best method was discovered by Graham, an English watchmaker. This consists of a glass cylinder containing mercury fixed at the end of a rod of steel or dried wood, and as the mercury expands much more than the rod and cylinder, its expansion upwards elevates the centre of gravity as much as it is depressed by the elongation downwards of the cylinder and rod. The best watches and chronometers which *are regulated by* a balanced wheel, are also com*pensated by having* balls of metal soldered to two



PENDULUM.

strips which expand unequally, the most expansible being on the outside, so that as the mass of the wheel expands by heat these balls are turned inwards, so that the centre of gravity of the wheel retains its same relative position whatever be the temperature. On this principle, too, pyrometers and some kinds of thermometers are constructed. If two metals which expand differently by heat be firmly fastened together at their ends, it is evident that when they are heated the one that expands most will be bent into a curve, and the greater the temperature to which they are exposed the more will the metal which expands most be bent; and it only requires an index to mark the degrees of temperature corresponding to this increased curvature, for its indications to be nearly as accurate for very great, as those of the ordinary thermometer for ordinary, degrees of temperature. In the fixing of grates, boilers, bridges, &c., where the metal expands much more than the brickwork, it is necessary to allow space for the metal to expand, or it would force the brickwork or masonry asunder. In laying down pipes for water, gas, &c., it is also in all cases necessary to allow space in the joinings for this expansion, or they would be bent on increase of temperature and forced out of their proper position. Advantage is taken of the force with which metals contract in cooling, in the placing of the tires on wheels, they being placed on red hot and then being suddenly cooled, they are not only firmly fastened, but they also bind all the parts of the wheel firmly together.

Many metals, in passing from the liquid to the solid state, suddenly expand and then contract again on cooling; it is by this expansion, on assuming the solid form, that in castings the metal is forced into all the depressions of the mould, and the cast has a clear sharp outline; and on account of the after contraction in cooling, moulds for casts require to be made larger than the pattern, or they would be too small when cooled down. Metals that do not expand in becoming solid cannot have any delicate or sharp outline given by moulds, and therefore they must, when required, be stamped upon them by dies, as in coining. Bodies that conduct heat badly are very liable to fracture on being suddenly and unequally exposed to increase of temperature. This is especially the case with glass; so that on pouring hot water into an ordinary tumbler the inside of the glass expands suddenly, and with force sufficient to break the glass, before the outside of the glass has had the heat communicated to it by conduction. This liability to fracture is, of course, increased as the difference between the temperature of the glass and of the water; so that it is most likely to take place in cold weather. The thicker the glass, the more likely it is to break, as it takes longer time for the heat to pass through the glass and equalise the temperature. This is the reason why all retorts and glass vessels exposed to great differences of temperature should be thin, as then any change of temperature on one side is communicated to the other quickly enough to avoid fracture. The conducting power of glass is very much increased and its tendency to fracture from this cause lessened by the process of annealing, or causing the glasses, when first formed, to cool very slowly; and hence common glass, which has not thus been annealed, breaks very frequently with very slight change of temperature between its interior and exterior surface.

### QUESTIONS ON CHAPTER XVI.

1. How can we show that the amount of heat in any body cannot be known by the senses?
2. Convert 112° Fahrenheit to Centigrade.
3. Express 40° Reaumur in the Centigrade and Fahrenheit's scales.
4. How do we speak of *expansion*?
5. What is meant by *coefficient* of expansion?
6. How may the cubical expansion be determined from the linear?
7. What is the first effect of a sudden increase of heat in an ordinary thermometer?
8. Explain the construction of *the gridiron* pendulum.
9. On what property of metals does the distinctness of castings depend?
10. Why should glass retorts be thin?

## CHAPTER XVII.

Expansion of liquids. Freezing: Deep and Shallow, Salt and Fresh Water. Ebullition. Effect of Elevation. Expansion of Gases. Principles of Ventilation.

**Expansion of Liquids.**—The expansion of liquids is always given in terms of their cubical or total expansion; and from what has been stated respecting the thermometer, it will be evident that there is a difference between their absolute and apparent expansion—the latter being the difference between the expansion of the liquid and that of the vessel in which it is contained. As in the case of solids, there is great difference in the coefficient of expansion in different liquids. In passing from the freezing to the boiling point alcohol expands nearly $\frac{1}{9}$th of its bulk, oil of turpentine and ether about $\frac{1}{14}$th, water $\frac{1}{20}$th, and mercury about $\frac{1}{60}$th; so that alcohol expands more than twice as much as water, and more than six times as much as mercury. This large expansion of alcohol for difference in temperature makes it important to all kinds of dealers in spirits, in purchasing them, to calculate their bulk at a standard temperature, and then make a suitable allowance if they are measured much above or below that standard. Liquids expand more for equal amounts of heat at a high than at a low temperature, and often very unequally near their boiling and freezing points; and the great value of mercury for thermometers registering ordinary temperatures is, that from 36° C. to 100° C. it expands equally for equal amounts of heat.

Water increases in volume above or below the temperature of 4° C., or 39·2° Fahr. Below this temperature it increases in volume to 0° C., or 32° Fahr., when, under ordinary circumstances, it becomes solid with a sudden and great increase of volume. The force of this expansion is sufficient to burst any ordinary vessel in which it may be confined, and it very frequently *bursts water*-pipes and other vessels, in frosty weather, on that account. It is on account of water becoming gradually lighter *before* freezing that deep water rarely or ever freezes; for as it cools down towards 4° C. it sinks to the bottom and the warmer and lighter rises to the surface, so that the whole body of water must be cooled down to that temperature before freezing commences.

On this account shallow pools and the edges of lakes freeze first, and it is often dangerous for skaters to go near the middle of lakes, though the ice may be thick and safe near the edges. Salt water requires to be cooled down below the freezing point of fresh water in proportion to the quantity of salt it contains; so that salt-water lakes do not freeze so soon as those of fresh water. Some seas, as the Baltic, have less salt in proportion than the waters of the ocean generally, and on this account, and also on account of its being shallower, the Baltic freezes almost like a fresh-water lake. Running water rarely freezes, especially in the centre of the stream, for its continual motion serves to keep up its heat, and prevents its surface from cooling to the necessary temperature. If ice were not lighter than water, and when it was formed it sunk to the bottom, it would, by its accumulation, interfere with, or entirely suspend, many of the most important operations of nature. The formation of ice on the surface of lakes and rivers also prevents the water underneath from cooling down below 4° C.; and as this is a temperature at which fishes and other inhabitants of the water can live, it prevents their destruction, which must have taken place had the temperature of the water been reduced below the point necessary for their existence. The next important change, after freezing, that takes place in water and other liquids is that of *ebullition* or boiling. Water gives off vapour at all temperatures, and it passes by gaseous diffusion into air, but when the temperature is raised to 212° Fahr., or 100° C., the pressure of the vapour equals that of the atmosphere, so that a bubble of vapour has an elastic force equal to the atmospheric pressure, and will float on the surface of the water freely. This point, where the tension of vapour equals that of the atmosphere, is called the boiling point, and it necessarily varies really with the rise and fall of the barometer; so that the temperature at which water boils is higher in mines than at the level of the sea—generally higher in the northern than in the southern hemisphere, and, of course, becomes lower the higher we ascend, so that water boils at a much lower temperature, as has been practically proved by Professor Tyndall, and others, on the top of Mont Blanc and Mont Rosa, than at the level of the sea. Hence, with a good thermometer to determine the temperature at which water boils on the tops of mountains, a good approximation can be made of their height. For small distances above the sea, an elevation of about 600 feet lowers the boiling point 1°; so that at a height of 600 feet water boils at 211° Fahr.; at 1,200, 210° Fahr., &c.; but as each layer of atmosphere becomes rarer as we ascend, it is evident that in reality we must, as we ascend, pass through more feet, to lower it from 211° to 210° than from 212° to 211°, and still more to lower it from 211° to 210°, and so on, passing through more feet for every additional degree of temperature below 212°, at which water boils.

**Expansion of Gases.**—Gases expand in bulk much more than either solids or liquids, and they also, unlike those bodies, expand uniformly under equal conditions of temperature and pressure. Thus, under the ordinary atmospheric pressure, all gases expand $\frac{1}{273}$ of their bulk for each degree of temperature of the Centigrade, and $\frac{1}{490}$ for each degree of temperature of Fahrenheit scale. It will thus be seen that whilst the coefficient of alcohol, in passing from the freezing to the boiling point, is only $\frac{1}{9}$th, that of any of the gases would be $\frac{100}{273}$, or more than three times as great; whilst it would be more than twenty times as great as that of mercury. Consequently, if a cubic foot of air, or any other gas, be raised through 273° C., or 490° Fahr., it will just be doubled in volume, but it will not weigh more than before its density, for the same volume will only be one-half of what it was before it was thus heated. It follows, therefore, that if any portion of the air be heated, it will ascend, just as a cork ascends in water; and this is the true reason why smoke rises up chimneys, in opposition to gravity; for though the smoke itself is heavier than the air, yet the fire heating the air over it, causes it to ascend, and the current thus generated carries with it the particles of soot, &c., though heavier than the air itself, just as the current of a river carries along with it mud, stones, &c., and deposits them as a delta near its mouth. All proper ventilation, also, depends on this principle; in all cases where this is properly attended to, provision is made near the ceilings and roofs for the escape of the heated and vitiated air, whilst provision is made near the floors for the admission of purer, cooler, and heavier air. Ventilation, owing to many causes, is not, however, easy to manage without causing draughts which act prejudicially; if, however, in all ordinary rooms where a fire is burning, a small opening, protected by a grating, be made under the fireplace and connected with the open air, and another opening near the ceiling into the chimney, which can be closed when the fire is not burning, this would render pleasant, and provide with pure air, many rooms which, without some expedient of the kind, are generally filled with air too impure to be long breathed without injury to health.

### QUESTIONS ON CHAPTER XVII.

1. How is the expansion of liquids expressed?
2. What fluids expand most, and which six times less, for equal amounts of heat?
3. Why does shallow water freeze sooner than deep?
4. What is the temperature above and below which water expands?
5. How may the boiling-point of water roughly determine the height of mountains?
6. At what temperature would water boil 15,000 feet above the level of the sea?
7. How much do gases expand for each degree of Fahrenheit's scale? How much for each additional degree of Centigrade?
8. Why does smoke ascend the chimney?
9. Explain a good method of ventilation for ordinary rooms.

## CHAPTER XVIII.

Difference between CONDUCTION and CONVECTION. Good and Bad Conductors of Heat. Value of Different Kinds of Clothing. Heating of Public Buildings. Ventilation of Mines, &c.

**Conduction and Convection.**—Whenever heat is conveyed from part of a body to another, from molecule to molecule, without any relative change of their position, the body is said to be heated by conduction. It is in this way that all solids are heated, and they are divided into good and bad conductors according to the speed with which the heat is communicated from one part of them to another. As a rule, all metals are good conductors; for unless bodies conduct heat and electricity well they are not considered as belonging to the metals. The best of these, however, are gold, silver, and copper. As a rule, all organic substances, whether animal or vegetable, are bad conductors, whilst earths and other inorganic substances, not metallic, are neither very good nor bad conductors. Hence all articles of clothing, as silk, wool, hair, feathers, cotton, linen, &c., are bad conductors; though cotton and linen, the latter especially, are better conductors than the others. Wood and all vegetable fibres are bad conductors, though—as seen in the case of linen and cotton—they conduct it better than those, such as wool and silk, derived from the animal kingdom. We can tell, practically, good from bad conductors by touching them when they are either at a high or low temperature. Thus, if we entered a room the temperature of which was that of freezing, we might walk with our naked feet on the carpet or hearth rug, or handle the woollen curtains, without feeling much chilled; because they, being bad conductors, would not quickly take away the heat of those parts of our bodies in contact with them; touching the walls, mantelpiece, doors, &c., *would give* a sensation of cold, but not nearly to the *same extent* as touching the fire-irons, grates, &c., for *these, being* good conductors, would rapidly take away the heat from the parts of the body with which they were in contact. Similarly, if we entered a room raised to the temperature of 212° Fahr., the carpet, rug, curtains, &c. would not feel uncomfortably hot, for they would not quickly impart their excess of heat to the body, whilst touching the grates, stoves, fire-irons, &c. would give a sensation of heat sufficient to cause actual pain. The difference of feeling between putting on, in a cold atmosphere, articles of linen, cotton, and wool will also, in a similar way, show how much more quickly the former conducts heat away from the body. Clothing aids in keeping up the temperature of the body in a cool atmosphere chiefly by its not readily allowing the passage through it of the heat from our bodies into the air.

The difference between the conducting power of bodies receives many illustrations and is turned to important uses, both in nature and art. Nothing, for example, is more important to plants and animals than the preservation of their vital fluids from extremes of heat and cold; and therefore, not only are all animal and vegetable tissues formed of badly-conducting substances, but whenever they possess natural coverings those are composed also of non-conducting substances. Hence, wool, hair, feathers, &c., which compose most of the natural covering of animals, are amongst the worst conductors of heat, and for this reason are also the most valuable materials of which to form the clothing of man. The epidermis, also, of thick-skinned animals, such as the elephant, rhinoceros, &c., which are not so much covered, are themselves a sufficient protection to these animals by being non-conductors. The bark of trees is also a much worse conductor than the woody fibre beneath it, and by its non-conducting power often protects plants and trees from destruction by the frosts of winter.

Though all metals are good conductors, yet copper is a much better conductor than iron, and it is on this account that not only does water boil much quicker in *metallic than* in any other kind of vessel, but it will *boil much* more quickly in one of copper than in one of iron. When, however, heat requires to be gradually and slowly applied, as in baking, preserving, making soups, &c., then earthenware vessels, which conduct heat more slowly and gradually, are generally employed. If we want to protect any substance from changes of temperature, whether of heat or cold, we surround it with non-conducting substances. Hence, if we surround a vessel containing hot water with bran, sawdust, wool, &c., the water will remain hot a long time; and if we similarly surround a vessel of ice, the ice will be equally preserved from melting, the non-conducting substance round the vessel equally preventing the escape of the heat from the water, and the admission of heat from the surrounding air to the ice. Almost all bodies are rendered bad conductors of heat if divided into powder, as the powder contains, in its interstices, a large quantity of air, which is a non-conductor. On this account, red-hot cannon-balls may be conveyed in wooden carriages containing sand, or ashes, without injury to the carriage; and red-hot lava has been known to flow over ashes, underneath which was a bed of ice, without the ice being melted. Copper kettles, metal teapots, and other metal vessels used for holding hot water, have generally some non-conducting substance—as wood, bone, or ivory—inserted between the vessel and the handle, otherwise the heat from the contained fluid in the vessel would be conducted so quickly to the hand of the person holding the vessel that it would be painful to hold it. On account of air itself being a bad conductor, two or three articles of clothing are much warmer than one, though the one may be thicker, inasmuch as between each article is interposed a layer of air, which prevents the heat passing from the body into the atmosphere. Double doors and windows are often used in very cold climates, on this account.

Liquids and gases, on account of the mobility of their molecules, are not heated by conduction from particle to particle, as in solids, but the molecules first heated, on account of their increased elasticity and decrease of density, rise up from immediate contact with the source of heat and other molecules, denser and less elastic, descend to take their places. There is thus a constant current, on the liquid or gas being heated, of light elastic particles, and of denser and cooler particles downwards. Bodies thus heated are said to be heated by convection. Like, for instance, a vessel full of water or any other fluid placed over a common fire, the bottom and sides of the vessel get heated by conduction, and they communicate their heat to the molecules of the fluid in contact with them; but these molecules, instead of remaining in their original position, and imparting their heat to the molecules next them, move away, and the colder and denser molecules come down the centre of the vessel and take their places, so that there is a constant current of heated molecules upwards at the sides of the vessel, and a downward one of cool ones in the middle; and these currents continue till the whole mass of fluid becomes heated.

This principle is also applied to heating houses, public buildings, &c., with pipes to regulate the currents, so that those of hot water should pass around or under the rooms which they are required to heat. The boiler supplying the pipes is always at the base of the building, and the pipes are placed in any ascending direction that may be required, and connected with as many more cisterns above the principal one as may be requisite for safety and the regulation of the supply of water. When the boiler is heated the hot water ascends, and the cold from the upper parts of the building descends by its greater weight, so that a constant current of hot water is ascending, which can be drawn off by taps, where required; and by another system of pipes, connected with the lower part of the boiler, there is a stream of cold water descending, which can also be drawn off by taps, if required; only, where the water is thus drawn off, there requires some self-regulating system to supply to the boiler as much as is drawn off or wasted by evaporation.

A better illustration of the expansion of gases by heat cannot, perhaps, be given than one referred to previously, viz., the action of the sun on the equatorial regions, and the consequent expansion and rising of the heated air, causing the vast currents known as the trade winds, whilst these vast masses of heated air pass over the region of the surface of trade winds as upper currents, and then descend again, when cooled in the upper regions of the air, to form near the surface the north-westerly and south-westerly winds that prevail from the 30th to the 60th degree of latitude. In fact, all the winds, by whatever name called, have their origin in the unequal heating of the different portions of the atmosphere; and, as the atmosphere, notwithstanding all these currents, remains upon the whole unaltered in composition, density, or elasticity, we may always conclude that whatever may be the general character of the currents on the surface of the earth, if they are mainly in any one direction, there must be equal and contrary currents to restore the equilibrium in the higher regions of the air.

It is on this principle that the ventilation of mines and their freedom from accumulation of dangerous gases is conducted. In all cases there is an ascending shaft, under which a large fire is kept constantly burning, which heats the air and causes it to ascend, as in the case of an ordinary chimney. At another portion of the mine fresh and cool air is admitted, and the passage of this air is regulated by doors, which can be opened or shut so as to cause the current of cool air entering the mine to take any required direction, till after passing through and removing along with it the noxious gases, it passes from the mine up the ascending shaft with a velocity somewhat in proportion to the amount of heat generated by the fire below.

## CHAPTER XIX.

Specific Heat. Large Amount of Specific Heat of Water. Latent Heat. Differences between Northern and Southern Hemispheres. Freezing Mixtures. Radiation and Absorption of Heat. Dew: when most Deposited. Rock Salt: its action on Rays of Heat.

**Specific Heat.**—If three similar vessels of the same size be filled, one with water, another with iron, and a third with mercury, all of the same temperature, and exposed to the same source of heat till the temperature of the water is raised 1°, it will be found that the iron is raised through 9°, and the mercury through 30°. If the experiment be altered, and 1 lb. of water be placed in the first vessel, 9 lbs. of iron in the second, and 30 lbs. of mercury in the third, it will be found that when the same amount of heat is applied to each, they will be raised equally in temperature; so that the heat that will raise 1 lb. of water one degree, will raise 9 lbs. of iron or 30 of mercury also through one degree. It is thus seen that bodies possess very different capacities for heat, some requiring much more than others to raise them through the same degrees of temperature. The same fact may perhaps appear more clearly by pursuing a different method. If we mix together 1 lb. of water at 100° with 1 of 50°, the result will be 2 lbs. of water at 75°, which is a mean between 100° and 50°; but if we mix 1 lb. of mercury at 50° with 1 lb. of water at 100°, the temperature of the mixture will not be 75° but 98·4°; so that, whilst the water has only lost 1·6° of its heat, the mercury has gained 48·4°, or 30 times as much as the water has lost; and if the same experiment had been performed with 1 lb. of iron and 1 lb. of water, it would have been found that the iron would have gained 9 times as much as the water had lost.

It has been previously stated that the atoms of all bodies are believed to be of the same size, but to differ in *weight; and* Dulong and Petit discovered this *remarkable law* with regard to specific heat, that the atomic weights of all simple bodies multiplies by their specific heat as a constant quantity, or, in other words, that the specific heat of bodies is always inversely as their atomic weights, and that consequently the atoms of all bodies require the same amount of heat to raise them through the same degrees of temperature. This law, however, applies to bodies under the same conditions; thus, the specific heat of a solid or a gas is less than that of a liquid, as is remarkably shown in the case of water, the specific heat of which in a liquid condition is nearly double that of its specific heat either as ice or steam. Under the same conditions, however, this law is found to be universally true, thus as the atomic weights of hydrogen, nitrogen, and oxygen are 1, 14, and 16 respectively, so their specific heats are as 1, $\frac{1}{14}$, and $\frac{1}{16}$; and it would take, therefore, 16 times as much heat to raise any given weight of hydrogen 1° in temperature as it would to equally raise the same weight of oxygen.

Water, which of all solid and liquid bodies possesses the largest amount of specific heat, is always taken as the standard with which to compare the specific heat of other bodies; but for gases it would be much simpler to take hydrogen as a standard, and then the simple division of the specific heat of hydrogen by the atomic weight of any other gas would at once give its specific heat. The large specific heat of water is one of the most important means of tempering the vicissitudes of heat and cold, and equalizing the temperature, especially in the neighbourhood of large bodies of water.

**Latent heat.**—If 1 lb. of ice of 12° Fahr. temperature be gradually raised to 32°, thus absorbing 20° of heat, it will be found, before any additional increase of temperature is indicated by the thermometer, to absorb 7 times as much, or 140° of heat; and then the ice will be converted into water of the same temperature as the ice. If the heat be still continued, the water will then gradually rise again in temperature till it come to 212° Fahr., when it will again remain stationary, and continue so till it has absorbed 967° of heat, when it will be converted into steam of a temperature of

212° Fahr.; and then, if the heating power be still applied, the temperature of the steam will steadily rise above 212°. In this experiment no increase of temperature took place in the ice above 32°, and no increase took place in the temperature of the water above 212°. It appears, therefore, that the 140° of heat, in the first case, was employed in converting the ice into water, and the 967°, in the second case, in converting the water into steam; and these amounts of heat, of which no evidence was given by the thermometer, are said to be *latent*, or concealed, and thus water is really a compound of ice and 140° of heat, and steam a compound of water and 967° of heat. Before water can be again converted into ice it must, therefore, give up 140° of heat, and before vapour can be condensed into water it must equally give up 967°.

This experiment might be conducted with most other bodies in a similar way, and with similar though not equal results; but it is believed that as by the oxyhydrogen blow-pipe and the voltaic battery most of the metals previously considered incapable of fusion have been melted, so those not as yet fused may be so when methods are discovered of producing a sufficiently high temperature. Each substance has, however, a constant temperature at which fusion commences, and, as in the case of ice, the temperature does not rise sensibly till the fusion is complete. Though, therefore, the latent heat of water is greater than that of any other substance, yet in all cases of liquefaction a certain amount of heat is rendered latent; and generally this amount of latent heat is proportionate to the capacity for heat of the substance thus liquefied. The temperature of solidification and that of liquefaction are of course the same: thus ice melts and water freezes at 32° Fahr., and hence the fusing point of substances generally liquid, as mercury 38° Fahr., oil of vitriol 30° Fahr., and bromine 9·5° Fahr., are generally spoken of as the temperatures at which they become solid, or their temperatures of *solidification*. This shows the immense cooling *effect of evaporation*, as it requires nearly as much amount of heat to convert one gallon of water into vapour as to raise 5½ gallons from the freezing to the boiling point. On a large scale we see the effect of this as exemplified in the northern and southern hemispheres. There is three times more land in the northern than in the southern hemisphere; and if we divide the earth into two hemispheres, taking England as the centre of one, and our antipodes as the centre of the other, we shall have 46 millions of square miles of land in one, and only 6 millions in the other. Now the amount of evaporation in similar latitudes will evidently be in proportion to the amount of surface of water, and there will be, consequently, much more evaporation in the southern than in the northern hemisphere, and again, much more in the hemisphere of which our antipodes is the centre than in that the centre of which is England.

This is so well understood that the southern hemisphere has been compared to the boiler of an engine, and the northern to the condenser; for where there is the greatest amount of land, especially of a mountainous character, there the winds in passing over it will be chilled and its vapour condensed, and fall in the form of snow, hail, or rain. This accounts, then, for the southern hemisphere being so much colder upon the whole than the northern, and also for the fact that, in the northern hemisphere itself, the western portion of Europe has the highest temperature, in proportion to its latitude, of any portion of the earth's surface, and that the line of greatest heat is not only generally north of the equator, but that it comes farthest to the north in the longitude of Europe. As the rain that falls on the earth's surface must either run off by natural or artificial drainage to the sea, sink into the earth to appear again as springs, or be raised again by evaporation, we can easily see how important it is in a cool and moist climate to provide good drainage, to prevent the reduction of temperature that must take place where, the drainage being bad, the greatest quantity of the rain has to be reconverted into vapour where it falls. The malaria of the Pontine Marshes, and the low fevers and agues that prevailed so extensively in the fens and marshes of Lincolnshire, the marshes of Essex, Gloucestershire, &c., whilst they were undrained, and which have now almost or entirely disappeared as they have been better drained and cultivated, are all proofs of the evil effects produced by the chilling action of excessive evaporation. On a smaller scale we see this in the often fatal effects of sleeping in damp beds, putting on wet linen, or keeping it on after it has been wetted by exposure to rain, dew, &c.; for in all these cases the heat required for the conversion of the water into vapour is abstracted from the body, and thus reduces its temperature, so as to produce rheumatism, ague, fever, colds, and other forms of disease. This chilling effect of evaporation has also been turned to useful effect, as in cooling wines, &c., by placing a moist cloth round the vessel containing it, and thus abstracting the heat by the conversion of the moisture in the cloth to vapour.

All freezing mixtures depend on this principle, and we cannot put even a small quantity of salt or sugar into soup or tea without reducing their temperature, a certain quantity of the heat of the liquid being necessary to liquefy the sugar or salt. It was by mixing salt and ice, which by their chemical action on each other caused liquefaction, that Fahrenheit obtained a temperature which he made the zero of his scale, and, by combining substances of greater chemical activity, a much lower temperature can be obtained. Thus, a mixture of calcic chloride and snow will, if the vessels in which the mixture is made and the chloride itself be cooled down to the temperature of the snow before making the experiment, produce a temperature from 45° to 50° below the zero of Fahrenheit. The ordinary machines for making ice consist of a vessel containing the water to be frozen, surrounded by another containing the freezing mixture, the whole being surrounded by some non-conducting substance to exclude the heat of the atmosphere. This freezing mixture generally consists of 2 parts of snow or pounded ice and 1 of salt, or of sulphate of sodium and hydrochloric acid.

**Radiation and Absorption of Heat.**—A body is said to radiate or give out heat when it imparts motion to the molecules of surrounding bodies, and to absorb heat when surrounding bodies impart motion to the molecules of which it is composed. In all cases the radiating and absorbing powers of bodies are equal, and those which become hot in the presence of a source of heat with the greatest rapidity will radiate that heat and become cool the soonest when the source of heat is withdrawn. In all cases, too, bright and polished surfaces which reflect light and heat most readily are the slowest to become hot when exposed to the action of a source of heat, and the slowest in cooling when they are once heated. Solid bodies, too, in all cases, receive or absorb heat, and also radiate their heat much more readily than liquid ones, and, consequently, large masses of land become hotter during summer, and colder during the winter, than islands; and hence the severity of continental as compared with the mildness and equality of insular climates. The vapour in the atmosphere also absorbs heat, and thus itself becomes heated by the passage through it of the sun's rays. This is the true reason why there is not only much less difference between the temperature of summer and winter, but also between that of day and night, in regions where the air generally contains a large portion of vapour, than in regions where the air is comparatively dry. In the centre of Australia, and generally in arid and desert regions, the heat of the sun is almost intolerable during the day on account of the dry air allowing the sun's rays to fall upon bodies with all their force; whilst in the same places, after the sun has set, so rapidly does the earth radiate its heat that, as Dr. Livingstone found in several places in Africa, a day of intolerable heat was followed by a night during which the air near the earth was cooled down below the freezing point of water. It was on this account that Professor Tyndall, to whose discoveries we owe most of our knowledge on this subject, found the direct rays of the sun to fall upon him through the dry air of Mont Blanc with a force almost unbearable, whilst no sooner was he sheltered from those direct rays by a projecting rock than he found the air to be really cold. Travellers in the centre of Australia, also, have experienced their greatest difficulties from this cause, and its effect generally on climate is one of the most powerful in existence, with the exception of distance from the equator, and height above the level of the sea.

Dew is a deposition of particles of water upon bodies which have been cooled down below the temperature at which the surrounding air is able to retain its vapour in an invisible form. It is produced in the greatest abundance when there is the greatest difference between the temperature of the day and night, and upon those bodies which radiate their heat with the greatest rapidity. During the night the air near the surface of the earth is constantly much lower in temperature than that even only a few feet above it, and this chilling of the air is, of course, greatest on clear and cloudless nights, for then nothing prevents the radiation of heat, and the consequent cooling of bodies on its surface. The deposit of dew is, of course, nearly quite prevented in windy weather, as the air does not remain long enough in contact with the bodies on the earth's surface to be sufficiently cooled. Cloudy nights also prevent much deposition of dew, by preventing the radiation of heat from the earth, and, for the same reason, little dew is deposited on substances protected by overhanging buildings or trees, as they also prevent the escape into the air of the heat from bodies beneath them. Very little dew is deposited on bright and smooth surfaces, as they do not cool quickly by radiation. In all calculations respecting radiation and absorption of heat lamp-black is taken as the standard, and the power of other bodies compared with it. Generally, the darker and the rougher the surface of any body is the greater is its radiating and absorbing power, and the lighter and smoother the less its power either to absorb or radiate heat.

Kettles, pans, and all other vessels to which it is *desirable to impart* heat, should have their surfaces black and rough, and hence water will boil much more quickly in a kettle or pan covered with a layer of soot than in one bright and new; but if you want a vessel to retain the heat of any liquid contained in it, then the brighter and smoother the surface, and the longer will the temperature of the liquid be maintained. Thus, the housewife should keep the surface of her urns, teapots, and kettles, merely used for holding hot water, bright, and so should the engineer keep bright the steam pipes of his engine, whilst the stoves and pipes of hot-water apparatus should be rough and black.

Some bodies, as rock-salt, allow rays of heat from all sources readily to pass through them, whilst others, like glass, will readily allow light to pass through them, but almost entirely prevent the passage of the non-luminous rays of heat. It is on this account that glass screens protect us from the heat of the fire, a great part of which consists of obscure or non-luminous rays, whilst, at the same time, they allow us to see the cheerful light of the fire behind it. It is on this account, also, that hot-houses and buildings of all kinds with glass roofs become so quickly heated by the rays of the sun, for the glass admits the luminous rays of heat from the sun to pass freely through into the building, but when they are reflected back as obscure rays they cannot pass out again, and, consequently, the heat in the interior of the building rapidly rises above that of the outer air.

### Questions on Chapters XVIII and XIX.

1. Which of the metals are the best conductors of heat?
2. What are all articles of clothing?
3. What parts of the furniture in a room could we handle without injury at a temperature of 32° or 180°?
4. How can we prevent ice melting in summer?
5. Why are pieces of ivory or bone frequently put on the handles of metal teapots?
6. How are liquids and gases heated?
7. Explain the method of warming houses by hot-water pipes, and the method of ventilating mines.
8. What is the difference in specific heat between mercury and water?

9. **What is the latent heat of water and of steam?**
10. **Explain the difference in temperature between the northern and southern hemisphere.**
11. **Explain the composition and action of freezing mixtures.**
12. **What is dew? and when is it most copiously deposited?**
13. **Explain the difference between glass and rock-salt with regard to rays of heat.**

# DIVISION III.

## CHAPTER XX.

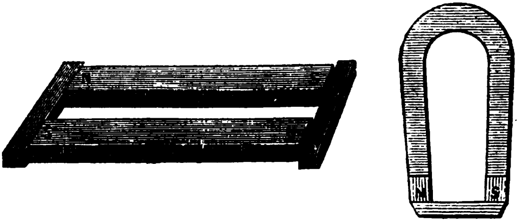
**Magnetism. Natural and Artificial Magnets. Magnetic Poles. Theories of Magnetism. Magnetic Fluids. Magnetic Currents.**

**Magnetism.**—This science is so called from the town of Magnesia, in Asia Minor, where, before the Christian era, it was discovered that certain ores of iron had the power of attracting other pieces of iron, and also of placing themselves, when freely suspended, so as to point north and south. This was called by the ancients **quick iron**, and superstitiously regarded by them as possessing almost all kinds of virtues, and capable of healing many diseases. It was called by our Saxon forefathers **lode, or lead** stone, from its pointing towards the north, as the north pole star was called by them lode star, and this term was corrupted into loadstone, by which name the natural magnet is now commonly known. It consists of a combination of two different oxides of iron, and is found as an iron ore, not only in Asia Minor, but in Norway, Sweden, the Isle of Elba, and in some parts of England. It is usually termed magnetic iron ore, and is manufactured into the best kinds of steel. In appearance there is nothing to distinguish it much from other ores of iron, and, were it not for its greater weight, it might be taken for an ordinary stone. In its most important use, as a guide to ships by pointing constantly *in one* direction, it was known to the *Chinese more than* 2,000 years before our era, under *he name of the* Chariot of the Sun; they giving its name to it from the end which pointed to the south, just as we gave it from the one pointing to the north. Navigation, before its discovery, was necessarily difficult and perilous, especially as when, during St. Paul's journey, "neither sun nor stars for many days appeared," for mariners in those cases, having nothing to direct their course, instead of going boldly out to sea, were compelled either to remain at anchor, or to keep near the land. It was not till the twelfth century that its use was known to Europeans; and only when Columbus sailed to the New World was it discovered that its direction was not always north and south, but that it varied more or less in direction from the true meridian.

**Magnetic Induction.**—The loadstone, or natural magnet, has the power of imparting its own properties to pieces of iron or steel with which it is brought in contact. If, for instance, a piece of soft iron be brought near the north pole of a magnet, it will itself at once be converted into a magnet, the end nearest to the north pole becoming a south pole, and the one most distant becoming a north pole. If then a second piece of soft iron be brought near the first, it will also be acted upon by the first piece of soft iron in the same way as the first piece was by the natural magnet, thus showing that, so long as the piece of soft iron is in connection with the magnet, it is converted for the time into a magnet itself. So soon, however, as the piece of soft iron is removed from the magnet it loses all its magnetism; but if, instead of a piece of soft iron, a piece of hard steel had been brought near the pole of a natural magnet, it would have taken some time before it had become a magnet, and after it had remained long enough to be converted into a magnet it would retain its magnetism for a considerable time, and, under suitable conditions, would become a permanent magnet.

Several different methods are adopted by which the natural magnet is made use of to form, from pieces of hard steel, different kinds of artificial magnets; and as those magnets can be made of a much more convenient shape, and are in every way better suited for illustrating the science of magnetism, they are generally used for all magnetic experiments, as well as for guiding vessels on the sea.

Artificial magnets are generally either long straight bars, called bar magnets; thin, broad in the middle, and tapering to a point at the end, and called magnetic needles; or bars bent into the form of a horse-shoe, and called horse-shoe magnets.



MAGNETS.

Bar magnets are always arranged in pairs, with the north pole of one opposite to the south pole of the other, and these are connected by pieces of soft iron, called armatures or keepers, because their inductive action on the bars enables them to retain their magnetism for any length of time. The horse-shoe magnets also have keepers which join their north and south poles; the needles are generally suspended on a pivot or axis at their centre, and require no keepers, as they, being free to move, are kept in the magnetic meridian, and retain their magnetism by the inductive action of the earth.

As it is found impossible to suspend a needle so that it can move freely vertically and horizontally at the same time; so those free to move horizontally are used to determine the magnetic meridian, and the angle it makes with the true meridian; whilst those suspended with power to move freely vertically are used to determine what is termed the dip, or inclination.

No matter what be the shape of the magnet, it is found that its power to attract pieces of iron, or to *act inductively* on other magnets, does not reside *equally in all* parts, but at two points near the ends.

This may be easily seen by placing a magnet on iron filings, when, on raising it, the two ends will be found thickly covered with the filings, whilst the middle will be quite free from them. Or if a small piece of soft iron be suspended from a string, and the middle of a magnet brought near to it, no attraction will take place; but on bringing either of the ends near to it, the piece of iron will be immediately attracted; and, if the magnet be a powerful one, this attraction will take place even when the magnet is at a considerable distance. That end of the magnet which, when it is suspended so as to be free to move horizontally in any direction, always points to the north is called the north pole, and that which points to the south, the south pole; the middle of the magnet, where no apparent action takes place, being called the magnetic equator.

The two poles of a magnet act alike in attracting pieces of soft iron; but they are unlike in the direction in which they point, and also in their action on other magnets. If the north pole of one magnet be brought near the north pole of another magnet it will repel it; but if near the south pole, it will attract it more powerfully than if it were soft iron. Similarly, a south pole will repel another south pole, and attract the north; so that in all cases **like poles repel each other**, and **unlike attract**; and whilst one pole always points to the **north,** the other as steadily and constantly points to the **south.**

If a magnet of any kind be broken, no matter into how many pieces, each piece will be a perfect magnet, having a north and south pole, with a neutral line in the middle. It is evident, then, that whatever change takes place in a piece of steel when it is made a magnet, that change is molecular, and that each separate molecule, if it could be separated from the surrounding ones, would itself be a perfect magnet. Now, as it has been stated previously, a molecule is the smallest quantity of matter capable of a separate existence; and there*fore, no matter* how small the fragments into which *you break* a magnet, each part, in proportion to its *size, will* retain the force of its magnetism. To show this practically, take a piece of steel-wire and magnetise it; place at the end of its north pole a piece of coloured paper to distinguish it, and then break it in two. On then bringing the two pieces to another small magnet, it will be found that the broken end connected with the north pole will be a south pole, and that connected with the south pole will be a north pole; and, if either of the halves be again broken, the same result will follow as long as any part of the needle is large enough to be broken.

**Theories of Magnetism.**—To explain the phenomena of magnetism two theories have been held.

First, that the molecules of all magnetic bodies are surrounded by a compound fluid of a highly rarefied kind; this compound fluid being itself composed of two fluids, named sometimes austral and boreal, and sometimes positive and negative, which are self-repellent, but which attract the opposite kind, and when united neutralize each other's action. When bodies are in their natural state, those fluids being neutralised by their union, give no sign of their existence; but when by any means they are separated, they are arranged on opposite sides of the molecules, all the austral fluid being on one side, and all the boreal on another. The power by which this separation of the two fluids is resisted by any body, or by which, when they are once separated, their reunion is prevented, is termed **coercive force.** This force has no sensible existence in soft iron, so that no sooner is a magnet brought near it than the two fluids are separated, and it assumes magnetic properties; whilst hard steel possesses it to such an extent that it requires some time before the fluids are separated, and when they are once separated they remain in that condition, so as to form permanent magnets.

The action of a magnet as a whole, then, according to this view, arises from the united action of its separate molecules; and the two points of the magnet which are the resultants of all these forces are the poles; whilst the middle of the magnet, where these orces are equal on each side, forms the equator, or neutral line. The reason why the north or south poles of a magnet attract a piece of soft iron, on this theory, is, that it first acts inductively upon it, separating the fluids which surround its molecules, attracting all that are unlike itself to its own side, and repelling those like itself to the opposite side; and that then these opposite fluids, being nearer each other than those of the same kind, attract each other with a force greater than those of the same kind repel each other; and, consequently, attraction is the result.

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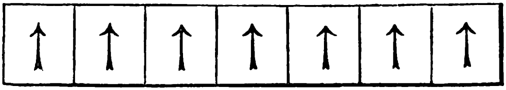
It is clear, then, according to this view, that the real force by which the magnet draws a piece of soft iron towards it, and by which it retains it when in contact, is the difference between its attraction for the fluid nearest and its repulsion for that further distant. But the greater the distance of the magnet from the piece of soft iron, and the less difference there will be between this attraction and repulsion; so that, if the magnet be at a great distance as compared with the size of the body acted upon, the two forces become so nearly equal that the difference cannot be detected. This is especially the case with the action of the earth on magnets; for so great is the distance of the poles of the earth from a magnet, compared with its size, that it is practically as far from one pole as the other, and therefore attracts one with no greater force than it repels the other; but, as both the attractive and repulsive force tend to direct the magnet, or place it in the magnetic meridian, so the earth's action on magnets is simply directive, and not attractive. To illustrate this, place some small magnetic needles on pieces of cork, and allow them to float on a vessel full of water, when it will be seen that they will all arrange themselves in the magnetic meridian, but will manifest no tendency to move in one direction more than in another.

A second theory, however, first propounded by Ampère, and now generally received, avoids the necessity for two fluids, by supposing that a simple fluid is always circulating round the molecules of bodies; that when bodies are in their natural state they run in all directions, and hence neutralise each other's action; but that in magnets, and other bodies under their influence, these currents are all made to run in one direction; and the resultant of all these small molecular currents is the same as if one current circulated entirely round the magnet, or round the body brought within its inductive action. Coercive force is, according to this view, the force which resists any alteration in these currents; so that, in a piece of soft iron, as it offers no resistance to the action of a magnet, they are at once made to run in the same direction as those of the magnet brought near it; whilst hard steel requires, in proportion to its hardness, a greater force to make these currents all move in one direction; but that when this takes place they continue to do so permanently when the influence of the magnet is withdrawn.



Currents moving in the same direction attract each other, and in opposite directions repel, so that all the laws of repulsion, attraction, &c., are explained by this theory as satisfactorily as by that of two fluids; and as this also seems to connect itself more closely with the phenomena of heat, light, and electricity, it is the one pretty generally received.

According to this theory, currents are constantly circulating round magnets, which, on looking at the end of the magnet pointing northward, appear to move from right to left, or in a direction contrary to the hands of a watch; whilst on looking at the end pointing south, they appear to move from left to right, or *in the same direction* as the hands of a watch. On bringing then the north and south poles of two magnets near each other, from whichever end you look the currents will appear to move in the same direction, and consequently they will attract each other; but on bringing two north or two south poles together, these currents will be in opposite directions, and will consequently repel each other. According to this view, currents are constantly circulating round the earth in a direction from east to west; and, as this is the way the sun appears to revolve round the earth, this theory still further connects the phenomena of magnetism with those of light and heat. The northern pole of the earth acts, therefore, as the south pole of a magnet, and its south as a north pole. In England we call that the north pole of a magnet which points northwards, and the one pointing south a south pole; but, as *unlike poles attract*, it is evident that the magnetism of the earth at its north pole must be different from the end of a magnet pointing in that direction. Hence, taking the earth as a standard, and calling the magnetism at its north pole boreal, and that at its south pole austral, the French term the end we call the *north* the *austral pole*, and the one we call the *south* pole they call the *boreal.*

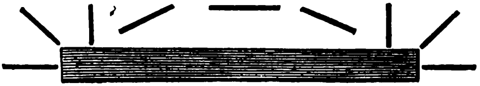
### QUESTIONS ON CHAPTER XX.

1. Where did the science of magnetism originate?
2. What is the natural magnet composed of?
3. What was it called by the Chinese, and when did it come into use in Europe?
4. Explain the different kinds of artificial magnets.
5. Where is the principal power of a magnet? Where does it exercise no power?
6. In what are the two ends of a magnet alike? and in what do they differ?
7. What is the result of breaking a magnet into two or more pieces?
8. Explain the theory of magnetic fluids.
9. What is meant by coercive force?
10. Explain Ampère's theory of magnetic currents. When do these currents *attract*, and when *repel* each other?

## CHAPTER XXI.

Terrestrial Magnetism. North and South Poles. Inclination. Declination. Intensity. Mariner's Compass. Action of Iron Ships on Compass. Diamagnetism: its Connection with other Sciences, &c.

THERE are many reasons for considering the earth to act as a large magnet, and nearly the whole science of magnetism depends upon that assumption. The simplest and most convincing reasons, however, for concluding that the earth itself is a magnet are, first, that in all important respects the action of the earth upon other magnets resembles that of a large magnet upon smaller ones brought near it. If a small dipping needle be placed over the centre of a long bar magnet it will stand perfectly horizontal; and if it be then gradually taken towards either end it will begin to dip more and more, till, when it comes over either pole, it will be quite vertical. The place in the middle of the bar, where the needle was perfectly horizontal, is called the equator; and the two ends where it was vertical, the poles. In these respects, the earth acts towards other magnets just in the same way. There is, near the geographical equator, but not coinciding with it, a line extending round the earth, where a dipping needle will be perfectly horizontal, and as the needle is moved away, north or south, from this line, it dips more and more, till at last in latitude 70° N., and longitude 96° 45′ W., in Boothia Felix, it stands vertical; and this is, therefore, the north magnetic pole. Another similar pole is supposed to exist, though it has not actually been visited, south of Australia, in latitude 75° 30′, and longitude 154° E. Secondly, that not only does the earth act as a large magnet on other magnets, but it also acts similarly



MAGNETIC BAR.

upon magnetic bodies, inducing magnetism in those exposed to its action, just as if they were exposed to the action of any other natural or artificial magnet, producing this effect at once upon soft iron, but acting more slowly and permanently upon hard iron and steel. Thus, if a long bar of soft iron be placed in the direction of a dipping needle in the magnetic meridian it will at once be converted into a magnet; the end dipping downwards in the northern hemisphere becoming a north, or austral, pole, and the one upwards a south, or boreal, pole; and on removing it from its position it at once loses its magnetism; and if it be reversed in position the poles are equally reversed. If, however, a bar of steel be similarly placed, it will take some time before it become a magnet; and if two equal steel bars are so placed, and then connected with armatures, the magnetism thus imparted to them will be permanent. It is this action of the earth that has imparted permanent magnetism to the loadstone, and which frequently also imparts magnetism to tools and iron instruments of all kinds accidentally placed in the magnetic meridian.

It is only recently that the magnetism of the earth has been carefully studied; and this has been done by systematically determining at various points on its surface what are termed the magnetic elements, viz., Dip, Declination, and Intensity; and also carefully ascertaining any changes which take place in them, whether those changes be daily, yearly, or of longer periods.

**Dip, or Inclination,** is the angle which a dipping needle makes with the horizon.

The magnetic equator is a great circle passing round the earth, and crossing the geographical equator at two points, at an angle of about 12°. It coincides pretty accurately with the line of greatest heat; and what are termed *Isoclinic* lines, which connect together all places where the dip is equal, run round the earth, *nearly,* but not quite, parallel with the isothermal lines, or lines of equal temperature. The dip increases in going northward or southward from the magnetic meridian, and in most places in the northern hemisphere the dip is now decreasing steadily from 2′ to 3′ annually. It is now about 67° in London, and has been decreasing ever since 1680, when it was first accurately determined.

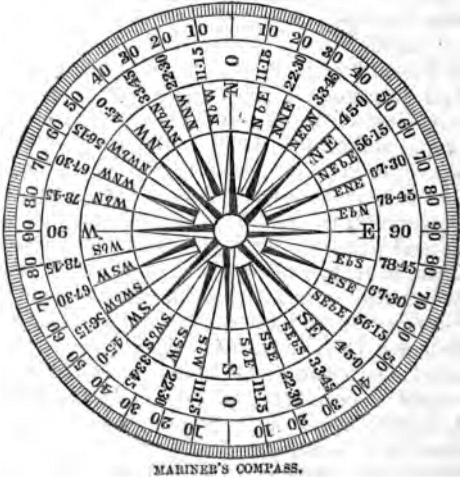
**Declination** is the angle which the magnetic meridian makes with the geographical meridian. All places where the magnetic meridian and the geographical meridian coincide, or when a magnetic needle, free to move horizontally, points exactly north and south, are joined together by what are termed agonic lines, of which there are two, an eastern and western. The eastern passes through Australia, the Indian Ocean, and the Caspian and White Seas; and the western passes through Brazil, the West Indies, and the American lakes to Boothia Felix. Besides these two, which are called the large agones, there is a smaller one on the east of Asia, which forms a kind of oval, and which is probably due to some local cause. These agonic lines do not remain permanently in the same place, and the causes which regulate their motion are entirely unknown. In the year 1660 the magnetic meridian coincided with the geographical one in London, and then went eastward till 1818, when the declination in London was nearly 24° 30′ W.; since then it has slowly returned westward, so that the declination in London is still decreasing, and is now only a little more than 20°; and should it continue to move westward at the same rate as it moved eastward from 1660 to 1818, it will coincide with the meridian of London again in the year 1976. Besides this secular variation, the declination of the needle is subject to annual variations, depending upon the seasons, and also to diurnal variations, both of which appear to arise from change of temperature.

The northern end of the needle in our hemisphere turns more to the west during the early part, and towards the east in the latter part of the day. It is probable that the diurnal and annual variations of *declination are both* owing to changes of temperature *in the atmosphere;* those portions which are most heated having less magnetic power than those which are cooler, just as a magnet at all times loses a portion of its magnetism when its temperature is increased, and gains it again when it cools. There is, in fact, such an intimate connection in the case of the earth between its temperature and its magnetism, that most scientific men believe that they are only different developments of the same cause; for as the magnetic equator coincides nearly with the zone of greatest temperature, so the magnetic poles, and points of greatest magnetic intensity, coincide very nearly with those parts of the earth where the temperature is the lowest, or those places which have sometimes been called the poles of greatest cold.

**Intensity.**—By this is meant the force of the earth's magnetism at any place, and it can be determined in the same way as the force of gravitation; for as when a pendulum is drawn aside from under its point of suspension it is brought back with a velocity proportionate to the force of gravity, so when a magnetic needle is drawn from the magnetic meridian it returns with a velocity proportionate to the magnetic intensity. The force of gravity is always proportionate to the square of the number of oscillations of a pendulum in any given time, and the magnetic intensity is also always proportionate to the square of the number of vibrations of a magnetic needle in any given time; so that if in one place a magnetic needle makes 10 vibrations in a minute, and in another 11, the intensity of the earth's magnetism at those two places will be as 100 is to 121. It is evident that as the longer the pendulum the slower are its oscillations, so the larger the magnetic needle and the slower will be its vibrations. It is, however, difficult to obtain the exact number of oscillations of a dipping needle, and it is on this alone that the total force of the earth's magnetism can be exerted. It is, therefore, generally obtained from a declination or horizontal needle on which *only* a part of the earth's force is exerted; but as the *dipping* needle is horizontal at the magnetic equator, *there the* vibrations of a dipping needle and a declination needle are exactly equal, and represent the total force of the earth's magnetism. When the horizontal needle is moved away from the magnetic meridian the total intensity is obtained in all positions by dividing the square of the number of vibrations by the cosine of the angle of dip; and as this cosine is unity at the magnetic equator, and goes on decreasing with the dip, it follows that the total intensity is always greater than the horizontal intensity, excepting at the magnetic equator, where they are equal. The total intensity of the earth's magnetism is least at or near the magnetic equator, and increases generally with the latitude; so that it is less at Calcutta than at Naples, less at Naples than in Paris, less in Paris than St. Petersburg, and less at St. Petersburg than at Spitzbergen.

All places on the earth's surface where the magnetic intensity is equal are joined together by lines called *Isodynamic*, or lines of equal force. These are more or less parallel with the magnetic equator, and lines of equal dip, but do not exactly coincide with the latter, but do coincide pretty accurately with the isothermal lines, or lines of equal heat; thus showing a very close connection between temperature and magnetic force, the one decreasing as the other increases. The points of greatest magnetic intensity do not, however, coincide, as might have been expected, with the magnetic poles; neither is this intensity equal in the two hemispheres, but is greater in the northern and western than in the southern and eastern. Two points of greatest intensity exist in the northern hemisphere; one in America west of Hudson's Bay, and another in Siberia. Though the total intensity thus increases generally with the dip, the vibrations of a horizontal needle are quickest at the magnetic equator, and decrease with the dip; hence a horizontal needle will vibrate quicker at Calcutta than at Naples, quicker in Naples than Paris, and in Paris than St. Petersburg, &c.

**The Mariner's Compass,** so called from its great use to *guide vessels* on the sea, consists of a *magnetic needle balanced* on a pivot, and free to move horizontally in every direction. It was used in Europe as early as 1180, but the first well-established account of its use in guiding vessels was in the voyage of Marco Polo from the East Indies to Europe in the year 1260. It was not till the voyage of Columbus in 1492 that the declination of the needle was discovered, as up to that time it had been supposed always to point exactly north and south. Since that time many important discoveries and improvements have been made in it, and, as now used, instead of a simple needle the compass generally consists of two, placed parallel at a distance of 30° on each side of the north and south lines; or of four, two placed at a distance of 15°, and two at a distance of 45°, so as to have a mean distance of 30°. By thus having a compound instead of a simple needle it is found that several sources of error are avoided. This needle, whether simple or compound, is attached to a card, on which are marked the points of the compass; and this card is so balanced that it always remains horizontal, whatever be the motion of the ship.



MARINER'S COMPASS.

*So long* as vessels were built chiefly of wood, the *compass*, properly constructed, always showed pretty *accurately* the direction of the vessel; but even then, as a certain portion of iron was used in the vessel's construction, and as this iron was frequently by its position rendered magnetic by the inductive action of the earth, it caused frequently variations in the compass of as much as 2° or 3° more than the deviation due to the geographical position of the ship. The true reason for these variations, which had previously been considered due to the faulty construction of the compass, was first discovered by Captain Flinders in his voyage to Australia in the year 1801, and he discovered a remedy for this by placing pieces of iron above the compass in such a position as to counteract the effects of the bolts, &c., used in building the vessel, which were, of course, chiefly below it. But in iron ships so great is the action of the material of which the ship is built that in some cases it causes errors in the compass of 50° or 60°; and, in fact, unless some remedy could be provided for this kind of error, the compass would be practically useless.

It has been previously stated that soft iron, by the inductive action either of the earth, or of another magnet, becomes magnetic, but loses its magnetism at once when the inducing agent is withdrawn; whilst, on the contrary, pieces of hard steel are a long time before they become magnetic, and when once they become so they retain their magnetism permanently. But by hammering, or in any way causing the particles of either soft iron or hard steel to vibrate, they are partly moved from their natural position, so that the hard steel becomes a magnet much more quickly, and the soft iron is also made to retain its magnetism much longer. In the building of iron ships not only is iron used of nearly every degree of hardness, so that some portions resemble soft iron, some hard steel, and others partake partly of the properties of both; but the magnetism induced by the earth is very much increased by the hammering it undergoes during the time the vessel is being built, and also by the position in which the *ship is placed during* that time, with relation to the *magnetic meridian.* But the magnetism thus hammered into the vessel is the greatest part of it destroyed by the concussion of the waves, so that vessels whose compass has shown errors of 40° or 50° when first built have had those errors reduced to 5° or 6° during a single storm. On this account the means taken to balance the errors of the compass in new vessels have, when they have been speedily exposed to stormy weather, been worse than useless, and, in fact, have caused the destruction of the vessel. This was the case with a large vessel that left Liverpool with emigrants in 1854, and which was wrecked and many lives lost within two days on the coast of Ireland, owing to the indications of the compass having been rendered from this cause entirely useless. So well is this now known that no confidence is placed in the indications of the compass in new iron vessels placed in the ordinary position, it being simply used to give direction to the steersman; whilst a compass placed at the mast-head, where it is comparatively free from the action of the material of which the vessel is built, is depended upon for giving the true course of the vessel.

Dia-magnetism.—Even as late as 1845 bodies were all classed as *magnetic* or *non-magnetic*. All forms of iron and steel, and most of their ores, were the principal magnetic bodies, and of these only hard steel or cast iron were capable of being made permanent magnets. Cobalt, nickel, chromium, and manganese were known to possess magnetic properties, though the latter only in a very feeble degree. It is well known that if a magnetic body, longer in one direction than another, be placed between the poles of a magnet it will arrange itself so that the direction of its greatest length will be in a line joining the two poles of the magnet. It will, in fact, be made into a magnet for the time; the end near the north pole of the magnet being a south pole, and the other a north; and thus the two ends will each be attracted and drawn as near as possible to the poles of the magnet. Faraday, however, discovered that some bodies—especially bismuth and antimony—when placed similarly between the poles of a magnet, arranged themselves in a direction entirely opposite to the direction of magnetic bodies; their line of greatest length being at right angles to a line joining the poles of the magnet. Instead of being attracted, they were, in fact, *repelled* by both poles of the magnet. This discovery showed that the science of magnetism, instead of being confined to a few of the so-called magnetic bodies, really included almost all substances in its operations. By using powerful batteries he very much enlarged the number of the magnetic bodies, proving that many other metals besides those usually reckoned magnetic really possessed magnetic properties, and that this property was also possessed by several gases, especially oxygen. He also proved that those not attracted by a magnet, and therefore reckoned *non-magnetic*, were nearly all really repelled by it, and, consequently, instead of being unaffected thereby, as had previously been supposed, were really influenced by it, though in a manner entirely opposite to that of magnetic bodies. The most powerful *dia-magnetic* bodies are bismuth, antimony, phosphorus, zinc, and tin, but nearly all animal and vegetable substances are really *dia-magnetic;* so that if a tree, or a man, were freely suspended between the poles of a sufficiently powerful battery they would be placed *equatorially*, or, like bismuth, in a direction at right angles to a line joining the poles of the battery. Thus *dia-magnetism* seems to be opposed to magnetism, as heat is to cold; so that generally bodies, as they are raised in temperature, become more *dia-magnetic*, whilst magnetic bodies become less so; and it seems possible that, were the reduction of temperature sufficiently great, most bodies would become magnetic; whilst, on the contrary, it might be possible to raise the temperature of most magnetic bodies, so that they would manifest *dia-magnetic* properties.

Bodies may be *magnetic*, or *dia-magnetic*, too, according to the medium in which they are placed; for just as under the influence of gravitation a cork will rise *in water because* the water is more acted upon by gravity than itself, whilst it will sink to the ground in air because the action of gravity is greater on the cork than on the air; so if a body be placed between the poles of a powerful battery in a medium more magnetic than itself it will appear to be repelled by the magnet and act as a dia-magnetic body, whilst if placed in a medium less magnetic than itself it will be attracted and arrange itself with its longest diameter in a line with that joining the poles. Air is magnetic, owing to the oxygen contained in it, whilst water is dia-magnetic; and gold, or arsenic, which appear dia-magnetic in air and set equatorially between the poles of a magnet, if placed between the poles of a battery in water will appear to be magnetic. Glass, also, which in air appears sometimes magnetic and sometimes dia-magnetic, will set axially like iron in pure water, but in water containing a solution of iron will set equatorially and act in every respect like a dia-magnetic body.

### QUESTIONS ON CHAPTER XXI.

1. Give the principal reasons for considering the earth as a large magnet.
2. Where are the magnetic poles?
3. What are the magnetic elements?
4. Define dip, declination, and intensity. Where does a dipping needle appear horizontal?
5. Where are the lines called eastern and western agones? Did one ever pass through London?
6. How is the magnetic intensity of the earth at any place determined?
7. Where is the total intensity least?
8. Give an account of the *mariner's compass.*
9. Explain the action of iron ships on the mariner's compass.
10. Mention the discoveries of Faraday in connection with *dia-magnetism.*

## CHAPTER XXII.

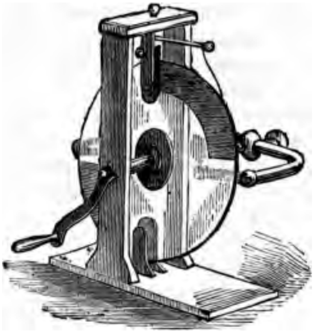
**Frictional Electricity: Historical Account of Principal Discoveries therein. Modes of Generating Electricity. Electrical Machines, Leyden Jar, and Explanation of their Action.**

THE word electricity is derived from the Greek *electron*, which means *amber*, as Thales, nearly 2,500 years ago, discovered that by rubbing amber with silk or wool it became capable of attracting light bodies. This was nearly all that was known respecting it till the end of the sixteenth century, when Dr. Gilbert of Colchester, who was physician to Queen Elizabeth, published a work on Magnetism and Electricity, in which he showed that this property was not confined to amber, but was possessed also by sulphur, wax, glass, and many other substances. The first electrical machine was made of sulphur, in 1672, and the first glass machine was not made till 1709. About 1740, Dufay discovered that substances, such as sulphur and glass, capable of being excited by friction, were also *non-conductors* of electricity when excited in them, whilst others, like the metals that could not be electrified, were capable of conducting it from one body to another. In 1746 a gentleman named Muschenbrock, famous for his scientific attainments, residing at Leyden, was electrifying some water in a glass vessel. To do this he put a nail through the cork of the bottle, to which was attached a chain to connect it with the water. Holding the bottle in his right hand, he held the nail towards the machine, so that the electricity from the machine might pass to the water; and when the water was thus charged he, with his left hand, took hold of the nail to remove the cork from the bottle, when he received a shock from the electricity passing through his body, that, in writing to Réaumur in Paris, he declared he would not experience again for the whole kingdom of France. The experiment, however, was repeated again in many parts of Europe, and by Franklin in America, who first gave a clear explanation of the shock thus experienced. In the year 1752, Franklin himself proved that the electricity of the clouds was in every respect similar in kind to that generated by an ordinary electric machine. He had been convinced himself that this was the case for some time, and had communicated his ideas to a gentleman in Paris, and also to the Royal Society of London, and was waiting for the building of a church with a high spire, in order to demonstrate it practically, when the ingenious idea occurred to him of elevating a kite during the passing of a thunder-cloud; and this experiment was entirely successful, so that he obtained sparks from the passing cloud similar to those obtained from an electrical machine. Carrying out the same idea a few years later, in 1760, he made the first lightning conductor, and proved that by means of these conductors buildings might be protected from the destructive effects of lightning.

Since that time many important discoveries have been made, and Professors Oersted, Ampére, and Faraday have almost demonstrated that electricity and magnetism are really but different manifestations of the same cause, and that the difference between conductors and non-conductors of the electric fluid are similar to the differences between soft iron and hard steel in their retention of the magnetic force.

**Electrical machines.**—The simplest and earliest mode of exciting electricity was by rubbing bodies, called electrics, with silk or woollen cloths held in the hand, and the earliest electrical machines were formed of balls of sulphur or glass, rubbed by silk or woollen cloths so held. Subsequently, however, it was found far easier and better to have the friction between the glass and the rubber produced by turning the glass by a handle, and causing it to press against the rubber as it revolved. An electrical machine for generating large quantities of electricity consists of the following parts:—

1st. The **rubber**, which is generally a cushion stuffed *with hair* or wool, and covered with leather, and when *used coated* with an amalgam of zinc, tin, and mercury, mixed into a paste with lard. This rubber is placed on an insulating stand, and made to press against the body of the machine by springs, so that its pressure can be increased or decreased at pleasure.

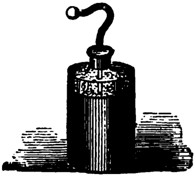


ELECTRICAL MACHINE.

2nd. The body of the machine, on the surface of which the electricity is to be generated by the friction of the rubber. This is made now generally of glass or ebonite, and may be either a cylinder or a plate; the first is the most convenient, and for its size the more powerful of the two; but as it is difficult to procure very large cylinders, when very great power is required plate machines are generally used. Those made of ebonite, in proportion to their size, are much more powerful than those made of glass, and as they are much less liable to attract moisture, they are much more certain in their action, and will probably in time entirely supersede those made of glass.

3rd. The conductor, which is always itself insulated, so as to prevent the electricity generated escaping, and so arranged that it can be put in communication with any body in which the electricity generated is to be confined for the purpose of experiment. The conductor immediately adjoining the machine is generally called the **prime conductor**, and it is furnished with teeth very near the body of the machine where the *electricity is* generated; these teeth acting as so many points for the ready passage of electricity between the prime conductor and the machine.

**The Leyden Jar.**—When a quantity of electricity is required for experiment, one or more Leyden jars are usually placed in connection with the prime conductor of the machine. The discovery of the Leyden jar, as has been previously mentioned, was accidental, and as usually made, they consist of wide-mouthed glass jars, coated inside and outside to within two or three inches of the top with tinfoil. Instead of an ordinary cork, a cover of well-dried mahogany is fitted into the mouth of the jar, through which a copper rod passes, terminating in a knob an inch or two above the cover, and having at the end inside a piece of brass chain which reaches to the bottom of the jar. A number of these jars placed together in a wooden box lined with tinfoil, and having these knobs joined by copper wire, forms an **electrical battery**, the power of which is proportionate to the size and number of the jars.


LEYDEN JAR.

**Explanation of the action of the machine and Leyden Jars.**—The electricity of the machine is exactly the same as that generated by rubbing a glass rod with a piece of silk or wool. The friction between the rubber and the body of the machine decomposes the electricity of the two, and positive is developed on the glass and negative on the rubber. If the rubber and the glass were both insulated, a few turns of the machine would charge them thus with opposite kinds of electricity, and no more would be produced, however long the machine was worked. When a quantity of electricity is therefore required, the rubber is connected by a brass chain with the ground, and the negative electricity formed on it passes at once to the earth, or positive passes to it from the earth, so that it remains thus in its natural condition. The positive electricity of the glass acts inductively on the prime conductor, attracting from its points the negative electricity, and leaving the conductor charged with positive. When, then, the knob of a Leyden jar is brought near the part of the prime conductor most distant from the body of the machine, the positive electricity of the conductor attracts the negative from the inside of the jar, and leaves it charged with positive. This positive then acts through the glass on the outer coating, attracting the negative and repelling the positive. If, however, the jar were insulated, the positive on the outside of the jar, though repelled, would have no means of escape; but when this outer coating of the jar is held in the hand, or connected in any way with the ground, the positive escapes and the negative remains on the outside, attracted by the positive inside the jar. There is thus accumulated on the inner and outer coating of the jar a quantity of different kinds of electricity in a state of tension, and when these inner and outer coatings are connected by any good conductor they rush together with a force proportionate to the quantity accumulated. It was the sudden rushing together of these electricities through the body of Muschenbroek that gave him such a violent shock, and with a battery sufficiently powerful this shock is sufficient to kill many animals, and even men.

## CHAPTER XXIII.

Elementary Facts connected with Frictional Electricity. Conductors and Non-Conductors. Distribution of Electricity. Induction Condensers, Electroscopes: Method of imparting Permanent Charge to, &c.

**Elementary facts connected with Frictional Electricity.**— 1st. ELECTRICITY IS OF TWO KINDS, and these two kinds *agree with* and differ *from* each other much in the *same way* as the two poles of a magnet. As no magnet can exist without a north and south pole, so it is impossible to generate one kind of electricity without generating an equal quantity of the opposite kind; and as a north or south pole will either of them equally attract pieces of soft iron, so a body charged with either kind of electricity will equally attract light bodies, such as bran, feathers, pith balls, &c. Again, as the north pole of a magnet will repel a north and attract a south, so two bodies charged with the same kind of electricity will repel each other, and those charged with opposite kinds will attract. As one kind of electricity was always found on glass, and the other on wax and resin, when the earliest discoveries respecting electricity were made, the one found on glass was called **vitreous**, and the other **resinous**. As, however, it is now well known that the electricity called resinous may be produced on glass by rubbing it with wool or fur, whilst that called vitreous may be produced on wax, these terms are now generally abandoned, the terms **positive** and **negative** being substituted for them. It is impossible to tell, in many cases of friction between bodies, which will be charged with positive and which with negative; but the fur of a black cat is the most positive, and next to furs, flannel, wool, and glass; whilst the one always charged with negative is gun-cotton, and next to this is gutta-percha, caoutchouc, sulphur, resins, &c.; whilst silk, cotton, metals, &c., are either charged with positive or negative according as they are rubbed with substances from the latter or the former list. Generally, also, the harder, smoother, and cooler of two substances is charged with positive, and the rougher or warmer with negative; so that if a rough and a smooth piece of glass be rubbed together, the smooth will be charged with positive and the rough with negative.

2nd. **Conductors and non-conductors.**—In the year 1729, Grey and Wehler were the first to conduct a charge of electricity from one point to another, and to *divide* bodies, according as they could or could not *conduct electricity* from one point to another, into *conductors* and non-conductors; and subsequently

Dufay showed that those bodies capable of manifesting signs of electricity, and which were called **electrics**, were also **non-conductors**; whilst those which could not be made to show any signs of electricity, and which were called **non-electrics**, were also **conductors**.

If any insulated conductor be charged with electricity, and connected by a good conductor with another insulated conductor of the same size, the electricity from the first body will pass along the conductor to the second, and the electricity will spread equally over the surface of the two bodies; but if they be joined by a **non-conductor**, no electricity will pass to the second body, and the first will retain the same as if it had not been touched.

A body separated by a **non-conductor** from other conductors is said to be **insulated**, and therefore non-conductors are frequently called insulators. Though bodies are thus divided broadly into **conductors** and **non-conductors**, there is no conductor so good but some electricity is lost in passing through it, and no insulator is so perfect but that it allows a certain quantity of the electricity to escape by it. Bodies are, therefore, frequently divided into **conductors**, **semi-conductors**, and **insulators**. The best conductors are the metals, and of these metals, copper, silver, and gold, are the best; after the metals, charcoal; then acids and saline solutions, sea and fresh water; next to these come living animals and vegetables, which are conductors simply because of the amount of water they contain; and, lastly, steam and gases, which contain a large amount of vapour, and which, also, conduct electricity more freely the more they are rarefied. Amongst semi-conductors are linen, dry wood, paper, straw, alcohol, oil, chalk, and marble. The best insulators are **dry air** and gases of all kinds free from moisture, ebonite, caoutchouc, gutta-percha, amber, sulphur, wool, hair, feathers, silk, and glass. It appears, therefore, that, amongst solid bodies, the best conductors of heat are the best conductors of electricity, and that the worst conductors of heat *are also the* best insulators of electricity; all *articles of clothing*, generally, being non-conductors of both, whilst linen, that conducts heat much more quickly than any other article of clothing, is also equally a conductor of electricity.

A thorough knowledge of the different action of conducting and insulating substances will explain easily most of the arrangements necessary for conducting electrical experiments. It is evident that all bodies on which it is desired to accumulate a charge of electricity must be insulated by being supported by insulating substances, of which ebonite is the best, though glass is commonly used on account of being cheap and easily attainable.

It also explains the necessity for keeping all the insulating parts of apparatus warm and dry, as any collection of vapour on their surface will convert them into conductors, and thus allow the electricity to escape. Whenever electricity is required for experiment it is necessary that the operator should have the power of discharging it instantaneously, but this could not be done unless it were collected on an insulated conductor; and this is the real reason why Leyden jars require to have their inner and outer surfaces coated by tinfoil or some other good conductor, so that, when the knob and any part of the outer coating of the jar is touched by a good conductor, the whole of the two opposite electricities rush together at once; but, were the surfaces non-conducting, the electricities would only combine from the parts actually touched. Thus, in the case previously mentioned, when an insulated conductor, charged with electricity, is connected with another insulated conductor in its natural state, the electricity is equally diffused over the two bodies; but, if the charged body be a **non-conductor,** no such result follows, the electricity only passing from the part of the body actually in contact with the conductor. It also explains why pith balls, or any other substance to which a charge of electricity is to be given, must be suspended *by threads* of silk or wax, whilst it is impossible to *charge them* when suspended by metallic wires, or even *by linen thread.*

*3rd.* **Distribution of Electricity.**—Electricity, when communicated to any conductor, spreads itself over the surface, and, unless in cases of extreme tension, does not penetrate at all into the substance of the body. This has been proved in various ways. If a hollow sphere, with openings in the side sufficiently large to admit a small piece of tinfoil, held by an insulating handle, be charged with electricity, and the tinfoil carefully placed inside, and then brought to an electroscope, it will give no signs of electricity, though, if the same tinfoil touch the outside, and be taken to the electroscope, the leaves will immediately diverge. If a sphere, charged with electricity, be carefully covered by two hollow hemispheres, coated with tinfoil and furnished with insulating handles, on removing the two hollow hemispheres it will be found that they have removed every trace of electricity from the sphere. Faraday, by connecting a conical-shaped muslin bag, like a butterfly net, with an insulated ring, found, when the bag was electrified, the electricity was always on the outside, and that, by turning the bag inside out, the electricity also changed, so as to be on the exterior surface.

Electricity, also, appears to distribute itself on bodies as far from the centre as possible; thus, in a sphere, every part of which is equally distant from the centre, it is distributed uniformly over its surface, but, in an ellipse, there is an accumulation at the two ends and less in the middle. In a circular disk the greatest quantity accumulates at the edges, and the least in the centre, and, on a square flat disk, the accumulation is greatest at the corners. It follows from this that, in a cube, there will be a double accumulation, and that, if any part be drawn out into a point, the accumulation of electricity will be greatest at that point, and, as its tendency to escape increases with the quantity accumulated, it will escape at these points more quickly than from any other part. In consequence of this, in ordinary states of the atmosphere, if one or two rods terminating in sharp points be placed on the prime conductor of an electrical machine, the electricity escapes as quickly as it is formed. If a rod be placed upon the prime conductor of a machine, and two wires terminating in fine points be placed at the top, with freedom to rotate round the rod as an axis, if the ends of the wires be bent at right angles and all in one direction, on working the machine the electricity will escape so rapidly from the points that the reaction of the air will make the wires rotate rapidly in the opposite direction. These facts all arise from the self-repellant nature of the electric fluid, which causes it to spread itself out as far as possible till it be prevented from proceeding further by some non-conducting medium. It also follows, from the same principle, that its power to overcome the resistance of that medium and escape will be greatest where it accumulates in the greatest quantity.

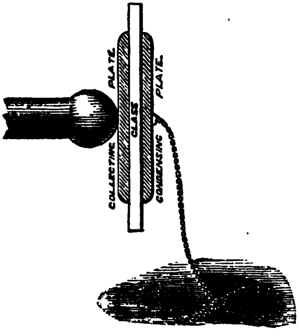
**Induction.**—If a body, A, charged with electricity, be brought near another body, B, in its natural state, it will act by induction upon it; and if the second body, B, be a conductor, on the surface of which electricity can move freely, the two fluids will be decomposed; that which is similar to that of the charged body, A, being driven to the end farthest from it, and that of the same kind as that on A being driven to the opposite end. This action of A upon B is, in fact, very similar in every respect to the action of the pole of a magnet upon a piece of soft iron. If the body, B, had been a **non-conductor**, this inductive action could not have taken place, as the electricity could not have moved freely on its surface, and, therefore, their decomposition would have been impossible, and B, notwithstanding the proximity of A, would have remained in its natural state.

If a metallic cylinder, two or three feet long, be insulated, and a ball, equally insulated and charged with positive electricity, be brought near one end, it will act by induction upon the cylinder; and if from the centre and each end of the cylinder pith balls be suspended by linen threads, those at the end nearest the ball will diverge with negative electricity, those at the end farthest from the ball with positive, whilst those in the middle will be unaffected. On removing the ball the electricities that had been separated by the inductive action of the ball will again reunite, and the pith balls will fall together. If, however, whilst the ball remained near the cylinder, the opposite end had been touched by the hand, or in any way connected by a conductor with the ground, the positive electricity would have been driven away from the cylinder. If, then, it were first disconnected from the ground, and then the ball removed, the cylinder would remain charged with negative electricity, and all the pith balls, at each end as well as in the centre, would diverge with negative electricity.

It is thus evident that a body, A, may charge a second body, B, with electricity by its inductive action without any electricity actually passing from A to B.

If the body on which inductive action takes place be an imperfect conductor, and, consequently, offer opposition to the reunion of the electricity separated by induction, this sudden reunion may materially affect the body on which the inductive action has been exerted. Thus, if. a man stand near the prime conductor of a powerful machine when strongly charged, it will repel the positive electricity from his body to the ground, but every time a spark passes from the prime conductor its inductive action will momentarily cease, and the positive electricity will rush again into his body, causing him to feel a sudden shock. In the case of a man or other animal thus acted upon by the inductive action of a cloud, this return to his body of the fluid when the cloud discharges its electricity is often so powerful as to be fatal, and constitutes what is termed the return shock. It was this inductive action on the body of a frog and its convulsions at each discharge of the prime conductor of a machine which, as will be more fully stated subsequently, led Galvani to the discovery of galvanism, or voltaic electricity.

**Condensers.**—A condenser is an instrument designed to collect a large quantity of electricity upon a small space, and derives its name from this property, just on the same principle as we speak of condensing any substance when we force a larger quantity into the same, or the same quantity into a smaller space. Its action depends entirely upon induction; and no matter what are the forms, or modes of arrangement, a thorough knowledge of inductive action will render the action of condensers of every kind easily understood. A condenser always consists of two **conductors** separated by a **non-conductor.** One of these conductors, called the **collecting plate,** is placed in connection with a source of electricity, and the other, called the **condensing plate,** is placed in connection with the ground. The use of the condenser is always to condense a greater quantity of electricity on the collecting plate than there is on the general surface of the source of electricity with which it is connected. The collecting and condensing plates may be perpendicular or horizontal, and they may be separated either by a thin film of air, a coating of varnish, or by thin glass. When the collecting plate is connected with a feeble source of electricity, the plates are usually separated only by air or varnish, for the charge would be too feeble to act through plates of glass; but when—as in the case of the Leyden jar, or the fulminating pane—the collecting plate is in connection with the prime conductor of a machine, then the condensing plate is usually separated from it either by glass or some other solid non-conducting substance, as otherwise the opposite electricities on the two plates would be likely to combine together. As the Leyden jar is perhaps the most important of the condensers in use, a description of its mode of action is given; and no matter how other condensers differ in form they all act precisely in the same way. A description of the form, and discovery, of the Leyden jar

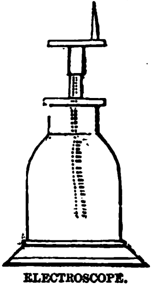


CONDENSER.

has been previously given; also it has been stated that it is most commonly charged from the prime conductor of an electrical machine, and that the action of the machine, when used in the ordinary way, is to attract the negative *from*, and repel the positive *to*, the distant end of the prime conductor and also to any body connected with it.

The use of the Leyden jars is to condense, on their inner and outer surfaces, a greater quantity of electricity than there is on a similar space in the prime conductor itself; or otherwise most purposes might be answered by simply enlarging the surface of the conductor. In the Leyden jar, then, thus used, and considered as a condenser, the prime conductor—or, rather, the machine—is the source of electricity, the inner coating of the jar the collecting, and the outer coat the condensing plate; the glass itself, of which the jar is made, acting as the non-conducting substance between them. As soon as the machine commences its action a certain quantity of positive electricity passes into the interior of the jar, similar in amount to that on the prime conductor. This acts by induction through the glass on the external coating of the jar, attracting the negative, and repelling the positive to the ground. This negative on the outside acts again, by induction, on the inside of the jar, attracting more positive and repelling the negative, which passes by means of the prime conductor, to neutralise the positive on the machine. This additional quantity of positive on the inside acts again on the outside, repelling more positive to the ground, and attracting more negative to the outer coating, and this again expels more negative, and attracts more positive to the inner coating; and so the action goes on, till the inducting action ceases, and then the jar is fully charged. The quantity of electricity in the jar greater than that in the prime conductor is called **bound,** or **latent electricity,** because it is held fast by that of the opposite kind on the exterior coating, and cannot escape even when a conductor is applied to it. That which it simply shares with the *prime conductor*, and which is free to escape, is hence *called free electricity*. When a jar is charged, therefore, in the ordinary way there is always an excess of electricity in the inside of the jar over what is on the outside, that on the outside being **all bound, or latent,** so that the jar may be handled by its outer coating without any spark passing; but on touching the knob of the jar connected with the inner coating a small spark will pass, which arises from the escape of the free electricity from the inner surface of the jar. It is easy to understand from this how it is impossible to charge an **insulated** jar, as then there is no way for the positive electricity to escape from the exterior coating, nor any means of obtaining more negative from the earth. The **fulminating pane** acts in every respect like the Leyden jar, only that it is flat, and held in the hand, instead of being round and being placed on the ground.

**Electroscopes** are instruments for detecting the presence of electricity, and may also be used for determining the kind of electricity with which any body is charged. Whatever form these instruments possess, they all depend in their action on the principle that bodies charged with the **same** kind of electricity **repel** one another; whilst those charged with **opposite** kinds **attract.** If two light pith balls be suspended together by silken threads, they will remain side by side till a body charged with electricity is brought near them, but then they will first each be attracted by the electrified body, and then, becoming charged with the same kind of electricity, they will be repelled by the body, and will also repel each other, so that they will remain separate, in opposition to the action of gravity, which tends to bring them together, till they gradually discharge their electricity into the air. If, however, they be suspended from any insulated conductor, they must be



ELECTROSCOPE.

suspended by linen threads, as then the electricity of the body will be communicated to them, and the distance they are separated will show roughly the amount of electricity existing in the body from which they are suspended.

Perhaps, however, as a simple and ever ready electroscope, nothing is better, or easier to obtain, than a small quantity of **bran**, or **sawdust**; for if a body be at all charged with electricity, and held over these, they will be alternately attracted and repelled by it, and will thus keep up a vigorous kind of dance between the table on which they are placed and the electrified body held over them.

For more delicate experiments, however, and for testing the kind of electricity with which any body is charged, an electroscope of more careful construction, and protected from currents of air, should be used. This generally consists of a brass rod having a broad disk at the top and two strips of gold-leaf suspended from the bottom, which is properly insulated and suspended in a glass case. Before the cap is fixed into the glass its interior should be thoroughly dried and filled with warm, dry air, and the mouth of the case hermetically sealed, so that there is no communication between its interior and the outer air. When proper precautions are thus taken, there is no moisture in the interior to take away the electricity, and the leaves when permanently charged will remain diverging, sometimes for hours. At the side of the glass case, and opposite the gold-leaves, are generally placed two strips of tinfoil connected with the ground, so that if the leaves diverge sufficiently to touch the sides of the jar, then electricity is discharged. To know whether a body is at all charged with electricity, it is only necessary either to touch the disk with it, or to bring it near it, for in both cases the leaves diverge, with the same kind of electricity as that with which the body is charged. To determine the kind of electricity, however, with which any body is charged it is necessary to first charge the electroscope permanently, *which is done* in the following way. Rub a glass rod with silk, and then bring the rod near the disk of the electroscope, but not touch it. It will separate the electricities of the electroscope by its inductive action, repelling the positive to the leaves, and attracting the negative to the rod and disk near it. Then touch the disk with the finger and the positive will be driven away to the ground. Remove then first the finger and then the rod, when the negative electricity that had been held bound in the rod and disk of the electroscope will be set free, and spread itself to the leaves, and they will diverge permanently with negative electricity. Then bring the body of which you wish to determine the kind of electricity it possesses near the disk of the electroscope, when, if it be charged with negative, the leaves will diverge more, but if it be charged with positive, it will, of course, act as the glass rod had previously done and attract the negative from the leaves, so that they will fall together. The best and most delicate electroscopes have a second disk which acts as a condenser, so that a much feebler charge will make the leaves diverge than would do so without its presence.

### QUESTIONS ON CHAPTERS XXII. AND XXIII.

1. Give an historical account of the origin and principal discoveries in frictional electricity.
2. State particularly Franklin's discoveries, and give an account of his experiment.
3. Describe the essential parts of an electrical machine.
4. Describe the Leyden jar.
5. What becomes of the negative electricity generated on the rubber?
6. What kind of electricity is generally on the *inner* and what on the *outer* coating of the jar?
7. What are the two kinds of electricity? and how do they act on each other?
8. Why have the terms *resinous* and *vitreous* been abandoned?
9. What substance is always charged with positive electricity?
10. Mention the principal *conductors* and *non-conductors* of electricity.
11. What is meant by a body being insulated?
12. How is electricity distributed on a cube?
13. Mention the *action* and *use* of points.
14. What is meant by *induction*?
15. Describe the *condenser*.
16. What are electroscopes?

## CHAPTER XXIV.

Atmospheric Electricity. Different kinds of Lightning. Thunderbolt. Thunder: Cause of its Peculiar Sound. Lightning Conductors: Description of, and Mode of Action. Electrical State of Clouds, and their Manner of Formation.

**Atmospheric Electricity.**—Thunder and lightning have inspired with awe and wonder alike the learned, and the ignorant and superstitious in all ages, and this was more especially the case when the causes producing them were entirely unknown. Even now, the rolling of the thunder and the lightning's flash will strike terror into the hearts of many, who would with the greatest coolness face much greater dangers. It was not till the discoveries of Franklin that it was established as a scientific fact that the electricity of the clouds that originated the thunder and lightning were similar in kind to the electricity originated by the electrical machine; and one valuable life at least was sacrificed in repeating Franklin's experiment, whilst forgetting the immense force of a discharge from such a large area as an ordinary thunder-cloud. Thunder-clouds are formed of dark masses of vapour charged with electricity, and, though charged with the same kind of electricity, prevented from dispersing, from the mutual repulsion of the particles by the inductive action of the earth. Lightning differs in appearance entirely according to the circumstances under which it is formed. The denser the air and the greater opposition it offers to the path of the lightning; and just as a river is frequently caused to turn out of its straight path and form two channels, on account of an accumulation of mud, &c., which it has itself brought with its waters, so the lightning in passing through the air condenses it in front, till its increased opposition causes the lightning to diverge from its straight path. This kind of lightning is called forked lightning, and is really the *most dangerous*, as it is always formed either by *discharge taking* place between the clouds and the earth, or between clouds very near the earth's surface. When, however, discharge takes place between clouds elevated considerably above the surface of the earth and where, by reason of the rarity of the atmosphere, it offers but small resistance to the passage of electricity, the lightning is popularly described as **sheet lightning.** This may take place at an elevation too great for the sound arising from the discharge to be heard on the earth; so that this lightning is often unaccompanied by thunder. When electricity passes through air very much rarefied, it commonly appears as broad bands, and those bands are frequently variously coloured. The aurora borealis, so well known in high latitudes, and which has recently been beautifully seen in the neighbourhood of London, arises from the passage of electricity in air very much rarefied. Every variety of lightning, from the forked lightning to the coloured bands of the aurora, can be imitated by sending an electric discharge through tubes from which the air has been more and more exhausted; its passage through the tube filled with dense air resembling forked, whilst as the density of the air in the tube is gradually lessened, it changes also gradually to the resemblance of sheet lightning; and, finally, as the exhaustion of the air becomes more complete, it assumes the form of the aurora borealis. A kind of lightning, called ball lightning, has frequently been described, and is popularly believed in, and called the **thunderbolt.** So firmly were the ancients convinced, not only of the **substance**, but also of the **metallic** character of those thunderbolts, that Vulcan, along with the gigantic Cyclops, were supposed to be employed in forging them for Jupiter. It is certain, however, that—no matter how well-authenticated some of the facts connected with them appear, or how deeply their existence has taken hold of the popular belief—that they can have no existence, except as meteors which may have fallen occasionally during thunderstorms.

**Thunder.**—The thunder which accompanies the discharge of electricity from the clouds is, doubtless, in every respect similar in its origin to the *snap* which is heard when a Leyden jar or a battery is discharged, or when a spark passes from the prime conductor of an electrical machine. In both cases it is owing to the concussion of the air, and though, on account of the terror it frequently causes, its violence is deemed greater than it really is, it has been heard for a distance of fourteen miles. The sound of artillery has, however, been heard for more than one hundred miles. We may therefore conclude that the concussion of the air due to the most violent thunderstorms is not so great as that caused by the discharge of artillery during any modern important battle.

Owing to the fact of the lightning being, for short distances, apparently instantaneous, and sound travelling only between twelve and thirteen miles in a minute, we are enabled to judge pretty accurately of the distance of the cloud from which the discharge proceeds. It is owing also to this, and to the great distance frequently traversed by the electricity during a discharge, that whilst the flash is instantaneous, the thunder comes to us as a prolonged peal. It is also evident that the peal will appear different according to the position of the person hearing it, with regard to the lightning's path. Echoes, also, of the original sound between the clouds and the earth, as they blend with, or interfere with each other, no doubt chiefly cause that peculiar rolling sound so characteristic of thunder.

**Lightning Conductors.** — The most important use that Franklin made of his discovery, that lightning and the ordinary electricity evolved by a machine were similar, was that of inventing conductors for the preservation of buildings from the destructive effects of lightning. He reasoned that, as ordinary discharges of electricity were always made along the path of least resistance, this would equally apply to discharges from the clouds, and consequently, that if a building were furnished with any conducting body as high, or higher than itself, the electricity, on its way to the earth, would select that conductor, and that thus the building would escape. If, for instance, a person stand near the prime conductor of a machine when in action, and hold his hand towards it, he will feel a succession of sparks and a stinging sensation therein; but if he hold in his hand a ball and a chain reaching to the ground, he will see the sparks pass to the ball, but cease to feel any shock, as the electricity will pass down by the chain, instead of by his body, to the ground. If, for the ball, he substitute a pointed rod near the conductor, the sparks will cease to be seen, and the electricity will pass silently between the point and the prime conductor. Lightning conductors consist necessarily of two parts, viz., the rod, or part projecting above the building, and the conductor, properly so-called, to convey the electricity between the rod and the ground. The rod should rise above the building to be protected from ten to thirty feet, according to its size; and if the building be very large, two or three rods should be used, as otherwise it would be necessary to elevate one rod too high for its stability in order that it might be sufficient for the protection of the building, as this protection is supposed only to extend over an area the radius of which is twice the height of the rod. It should be of a conical shape, and terminate in a fine point, which should be gilt, in order to prevent its becoming blunted by rust.

The most important use of this pointed rod is not that which was supposed at its first invention, or which is now generally entertained. The popular idea of a lightning conductor is, that it allows a safe passage for the electrical discharge to pass from the *clouds* to the *earth*. Its most important and general use, however, is exactly the reverse, viz., to allow the opposite kind of electricity to that with which the cloud is charged to pass from the *earth* to the *cloud*, and thus to restore the equilibrium without any electricity passing from the cloud to the earth. Suppose, for instance, a cloud charged with positive electricity to come near one of these conductors, it will act powerfully upon it by induction, repelling the positive to the ground, and attracting the negative to the point of the conductor, from which, as has been previously explained, it will pass rapidly and silently into the cloud, to neutralise the positive it has in excess. It is only, therefore, when the cloud contains more positive than the rod can thus neutralise that any of it actually passes to the earth.

**The Conductor** should be round, and of a diameter from half an inch to an inch. As copper is a much better conductor of electricity than iron, copper conductors were, at first, frequently used; but the passage of electricity acts injuriously upon copper, whilst it improves the conducting power of iron, so that now **galvanised iron** is nearly always used for these conductors. It is very important that the base of the conductor should be in connection with moist earth, or, still better, with a well, or a stream of running water. If it be impossible to have a well or stream of water for the termination of the conductor, it should be made to terminate in a hole filled with charcoal, as this, being a good conductor, acts in the same way as water. Dry earth being really a bad conductor of electricity, if the bottom of the conductor terminate therein, it will be useless, as it will neither allow the electricity to pass readily from the earth to neutralise that of the cloud, nor will it afford a ready means for it to escape, should it pass from the cloud by the conductor to the earth.

These conductors, when used to protect vessels at sea, are usually flexible chains, which pass from the rod, which is, of course, elevated above the highest mast into the sea. If the vessel be large there should be two or three rods, and, of course, connected with those a similar number of flexible chains, each passing into the sea.

In all ordinary states of the atmosphere it is charged with more or less positive electricity, whilst the surface of the earth itself is negative. The amount of positive electricity in the air increases as we ascend, and is generally greater in winter than summer, and also greater a little after sunrise in the morning, and about sunset in the evening, than it is either at noon or midnight.

Thunder clouds are of very different heights above the horizon, some having been seen not more than fifty or one hundred feet in elevation, whilst others have been known to be as high as 25,000 feet. The inductive action of the earth appears to increase when the air is filled with vapour; and this is supposed to be the principal cause of difference in the amount of electricity in the air. Clouds formed at great elevations are chiefly charged with positive electricity; but those that have been formed near the earth, as fogs, mists, &c., are often charged with negative, from their connection with the earth. It is mainly owing to the different elevations at which clouds are formed that they are charged with *opposite* kinds of electricity, though the *atmosphere, as a whole,* is generally positive. When clouds thus charged with opposite kinds of electricity are brought near each other they are attracted towards each other, and the opposite kinds of electricity also accumulate at the ends nearest each other, so that when they approach within distances which, of course, vary with the quantity of the electricity they contain, the two electricities rush together through the air, giving origin to the lightning, and the violence with which it rushes along also causes the sound which we term thunder. Thunder-storms, and the rain, hail, &c., accompanying them, of course owe their origin to atmospheric electricity; but this is also supposed to be at least one of the principal agents in the ordinary production of rain, hail, snow, &c.

### QUESTIONS ON CHAPTER XXIV.

1. Describe different kinds of lightning.
2. What causes the *aurora borealis?*
3. What is thunder?
4. Describe the different parts of a lightning conductor.
5. What is the principal use of the pointed rod?
6. Describe the precautions necessary in the arrangements of lightning conductors.
7. Describe the kind of conductor generally used for the protection of vessels at sea.
8. What is the general difference between the electricity of the earth's surface and that of the atmosphere?

## CHAPTER XXV.

**Galvanism, or Voltaic Electricity: Historical Account of its Origin. Difference between Voltaic and Frictional Electricity. Origin of Electrical Currents. Electro-Positive and Electro-Negative Elements. Proofs of the Existence of Electric Currents.**

**Galvanism, or Voltaic Electricity.**—This branch of electrical science owes its names to its two most illustrious discoverers, viz., Galvanism to Galvani, a professor of anatomy in Bologna, in Italy; and Volta, who was a physician and professor of natural philosophy at Pavia.

It was totally unknown till the year 1780, when Galvani observed convulsive movements in the legs of a frog placed on a table near an electrical machine every time a spark passed from the prime conductor. This was really due to the *return shock*, as has been previously explained; but Galvani having a favourite theory of his own, which he thought this and other experiments confirmed, was led to place frogs on the top of a conductor above his residence; and he found that every time there was an electrical discharge during a thunder-storm, the convulsive movements in the limbs of the frogs were observed. In 1786, having suspended some frogs by copper hooks to the iron railings in front of his room, he observed that in all states of the weather, whenever the wind caused the limbs of the frog to touch the railings, that these convulsive movements took place. The result of these and other experiments were published by Galvani in 1791, and he attributed these convulsions to **animal electricity.** He believed that the brain was the origin of this electric force, which was conveyed from it by the nerves to the muscles; the interior of the muscle acting as the inner coating, and its exterior as the outer coating of an ordinary Leyden jar. The electricity which, originating in the brain, was conveyed by the nerves to the muscles, Galvani considered was the source of all muscular power, and he consequently called it the *vital fluid*, He looked upon the metallic arc, whether consisting of one or two metals, as having no part in *originating* this power, but as simply acting the part of a *discharging-rod*, by which the two electricities were reunited, as in discharging an ordinary Leyden jar. These views were generally considered correct till, in 1792, Volta, who had repeated many of Galvani's experiments, came to the conclusion that, in the case of all his early ones, the convulsive movements were due to the action of ordinary frictional electricity, generated by the electrical machine, or originating in the atmosphere; and that in other cases, as in the suspension of the frog by copper hooks on the iron railings, the movements were caused by a force originating in the contact of the two metals. Volta argued that whenever contact was made between two different metals, they were thrown into a state of tension, and that this originated what he termed the **electro-motive force.**

A contest was carried on for several years between those who held the theory of Galvani and those who adopted the contact theory of Volta. Whilst this discussion was going on, however, Fabroni suggested **chemical action** as at least having something to do with the results obtained by both Galvani and Volta; but this at the time attracted little attention; and Volta, by the discovery of his pile in 1799, seemed to prove conclusively the truth of his reasoning; and it was almost universally adopted from that time till many years later, when the reasoning of Fabroni, Wollaston, Davy, and M. de la Rive, caused the chemical theory of the origin of the **electro-motive force** to be pretty generally acknowledged. They, by many experiments, showed that metallic contact alone was incapable of exciting the electro-motive force, unless the metals were placed in situations favourable to chemical action; and that when they are placed in gases, such as nitrogen or hydrogen, which exert no chemical action upon them, all signs of electricity disappear. In 1840 Faraday proved by a series of careful experiments that chemical action is the real source of all current *electricity*. Modern science has also proved incontestably that Galvani was not only right in many of his experiments, but also in his reasoning; and that all muscular movements are really due to the action of a force originating in the brain, and that this force is conveyed from the brain to the muscles by the nerves, the circuit being completed by another set of nerves, which convey impressions from the muscles to the brain.

**Galvanism,** then, is that form of electricity arising from **electrical currents,** which have their origin in chemical action, and more especially from that kind of chemical action which arises from the decomposition of metals. It is sometimes called **Dynamical** Electricity, because it deals with electricity **in motion,** whilst frictional electricity is called **Statical,** because it refers chiefly to the condition of **insulated bodies,** where the electricity remains fixed. It is true that frictional electricity moves with immense velocity along conductors, but this movement is instantaneous, and only takes place to restore the equilibrium, so that when discharge in this way takes place all signs of electricity vanish. In galvanism, on the contrary, the currents, instead of being **instantaneous,** may be kept up for **hours, days,** and **weeks,** and, so soon as the current ceases, all evidence of its action ceases with it. Movement, then, in a current is the normal condition of galvanic electricity, whilst **insulation,** or a state of **rest,** is the normal condition of frictional electricity.

**Origin of Currents.**—It being well established now that electricity is generated whenever chemical action takes place, and that electrical currents have their origin in chemical decomposition, it will be necessary briefly to give an explanation of the origin of these currents, or of the generation of what is termed **electromotive force.**

All compound matter is made up of molecules, composed of atoms of a different character, some of which are **electrically positive** and others **electrically negative,** and the union of these negative and positive atoms forms a compound molecule. Chemically, therefore, all the elements are divided into **electro-positive** and electro-negative, just as, with regard to heat and frictional electricity, bodies are divided into conductors and non-conductors. Just, however, as in the latter case, conductors and non-conductors gradually merge in those called semi-conductors, and differ greatly amongst themselves in conducting and insulating power, so the electro-positive and electro-negative elements possess these properties in very different degrees. For all galvanic purposes, however, the most decided electro-negative elements are oxygen, sulphur, chlorine, bromine, iodine, fluorine, phosphorus, and nitrogen, their decided negative character being in the order in which they are placed. Of the metals, the most decidedly positive are potassium, sodium, zinc, iron, copper, silver, gold, platinum, and carbon, the most positive being placed first. Hydrogen, which is now generally believed to be the vapour of a metal, is also classed amongst the positive elements, though it is less so than most of the other metals. Whenever two plates of metal, or of any other good conductor of electricity, are placed in a conducting liquid, the molecules of which are made up of electro-positive and electro-negative atoms, according to the difference in the positive character of these plates, the molecules are all placed in a state of tension, the most positive of these plates becoming charged with positive electricity at the end immersed *in*, and negative at the end *out* of the fluid; whilst the least positive plate will have the end *in* the liquid negative, and that *out* of the liquid positive. The molecules of the liquid between the plates will also be placed equally in a state of tension. or be what is termed polarized, all the electro-negative atoms being turned towards the positive plate, and all the electro-positive being turned to the negative one.

This tension, or polarization, will be the more complete according to the difference in the positive character of the plates, and, therefore, greatest between plates farthest distant from each other in the preceding list. Thus, the polarization, or tension, would be feeble be*tween zinc* and iron, greater between zinc and copper, and greatest of all between zinc and platinum or carbon. If the liquid in which the plates be immersed be water, which is made up of one atom of oxygen and two of hydrogen, all the oxygen atoms would be turned to the zinc, and the hydrogen atoms towards the negative plate. If sulphuric acid or hydrochloric acid, the sulphur and oxygen of the former, and the chlorine of the latter, would be turned towards the zinc, whilst those of hydrogen would be turned to the opposite plate. So long, however, as the two plates were prevented from touching, or unjoined by any good conductor, though this state of tension existed, no electric current would be generated; but, as soon as ever the two plates are made to touch, or are joined by a good conductor, the current commences; the negative element of the liquid, combining with the zinc, forming an oxide, a sulphate, or a chloride, of zinc, according as the liquid is water, sulphuric acid, or hydrochloric acid, whilst in each case the hydrogen is set free in the negative plate. A current, then, is set up in which the two kinds of electricity move in opposite directions, for, as stated, whilst in the liquid the positive hydrogen moves towards the negative, the negative oxygen, sulphur, and chlorine, each move in an opposite direction towards the positive zinc. To prevent confusion, however, the positive current is always the one spoken of, it being understood that there is always an equal negative current in the opposite direction.

The positive current, then, always flows in the liquid from the most positive towards the negative plate, and, out of the liquid, from the negative to the positive one. Though the greatest amount of electricity is generated when the plates differ most in their positive character, and potassium and sodium are each more positive than zinc, yet, as they each combine with oxygen in ordinary states of the air, they would be dissolved too rapidly to be of any permanent use, and, therefore, zinc, which should be coated with mercury to prevent waste, is always used for the positive plate. For the negative plate, though copper and iron, on account of their cheapness, are commonly used, yet the most powerful action arises when they are made of platinum or carbon.

**Proofs of the existence of Electric Currents.**—1st. If a piece of zinc and a penny be placed on the tongue, no action will take place till their edges are made to touch each other, but, as soon as the two metals touch, a peculiar taste is felt at once, arising from the dissolution of the zinc and the liberation of hydrogen on the tongue. Similar results, only a little more powerful, will be felt if a piece of silver, as half-a-crown, be used instead of the penny, and the taste will be still more decided if a piece of graphite be substituted instead of the half-crown.

2nd. If a strip of platinum and another of zinc be placed in a vessel containing dilute sulphuric acid, and they be joined together by a strip of copper wire, so that a line joining them shall be in the magnetic meridian, on bringing a magnetic needle over the current, instead of remaining parallel with the strip of copper in the magnetic meridian, it will be turned more or less at right angles to it, showing that the strip of copper under those circumstances possesses a power over the magnetic needle sufficient to overcome the directive action of the earth. If, then, the magnetic needle be placed *under* the strip of copper, it will be found that the needle will be still turned out of the magnetic meridian, but this time it will be deflected in a direction opposite to that in which it was deflected when placed above it. The following rule, first substantially given by Ampère, will always enable a person to know the direction in which the needle will be deflected. *Suppose yourself to be swimming with the current, and looking towards the needle, when the north pole of the needle will always turn towards your left hand, and its south pole towards your right.* On placing the needle equally above and below the fluid in which the plates are immersed, it will also be deflected, showing that the current passes through the liquid as well as through the connecting copper, and thus, in fact, makes a complete circuit.

3rd. If, after this action has gone on some time, the *fluid* and the zinc be carefully weighed, it will be found that the zinc is *lighter* and the fluid *heavier* than they were before the commencement of the experiment, and that the zinc has lost just as much as the fluid has gained. If, now, sulphate of copper be substituted for sulphuric acid, and the experiment be continued, it will be found that still the zinc has lost and the liquid gained weight, but that the platinum plate has also gained weight, and become coated over part of its surface with pure metallic copper.

4th. If, instead of uniting the plate of platinum with the zinc by a broad strip of copper, two strips are used, one attached to the zinc and the other to the platinum plate, and these two are joined by a fine platinum or iron wire, this wire will become gradually heated, and, in a short time, become red-hot, or even melted.

5th. If the plates be connected by a wire, and this wire be placed among steel filings, so long as the current passes along the wire the filings will adhere to it the same as to a magnet; but, if the circuit be broken, and the current cease to pass, the filings will instantly fall off, thus showing that the attractive power of the wire is entirely owing to the current.

6th. If the connecting wire be twisted in the form of a spiral round a piece of soft iron, so long as the current is passing through the wire the piece of iron will be converted into a magnet; and, if the coils of the wire be loose enough to allow it freedom of motion, it will place itself in the magnetic meridian, and its north pole will attract the south and repel the north pole of another magnet, just in the same way as a permanent magnet; but the moment the current ceases all signs of magnetism cease with it.

If, however, instead of soft iron, a piece of hard steel be placed similarly in the coils of the wire, if the action be continued long enough, the piece of steel will be converted into a permanent magnet.

The preceding and many other experiments prove that there is a *reality* in the electric current, and, as most of them may be imitated to a certain extent by suitably arranging the apparatus of frictional electricity, they thus, also, show that they are also due to electric action, and, consequently, that galvanic or voltaic and frictional electricity are only varying forms of one and the same cause. In a state of tension, indeed, before the junction of the metals, it can be shown by a condensing electroscope that the part of the zinc plate out of the liquid is charged with negative, and the part of the platinum charged with positive, though all signs of statical electricity vanish when the junction of the metals is effected, and the circuit closed. Every time, however, the circuit is broken, then the plates or terminal wires again give evidence of being in opposite electrical conditions.

The great difference, then, between frictional and voltaic electricity seems to consist in this, that the former is small in amount, but of great tension, and thus capable of overcoming obstacles in its path, which it is utterly impossible to overcome by the greatest accumulation of voltaic electricity; whilst the latter can be developed in enormous quantities, but is of such feeble tension that it can only move from molecule to molecule in a regular current, and is unable to overcome obstacles which even the smallest quantity of frictional electricity would easily surmount. Thus, electricity, generated by a powerful machine, will give sparks of ten or twelve inches in length, whilst it would require a powerful battery of 1,000 galvanic cells to obtain a spark the one-thousandth of an inch.

### Questions on Chapter XXV.

1. Describe Galvani's experiments, and the theory he founded thereon.
2. Describe the theory of Volta.
3. What is galvanism? and how does it differ from frictional electricity?
4. What are the most electro-positive and the most electro-negative substances?
5. What is the result of placing two different metals in a conducting liquid?
6. In what direction does the positive current always flow?
7. Give Ampère's rule for determining the direction of the current from the deflection of a magnetic needle.
8. Give proofs of the existence of a magnetic current.

## CHAPTER XXVI.

**Different Methods of Originating the Voltaic Current. Volta's Pile: Wollaston's Battery: Smee's Battery. Batteries with Two Fluids: Daniell's, Grove's, and Bunsen's. Instrument for Detecting and Measuring the Strength of Currents. The Galvanometer and Voltameter.**

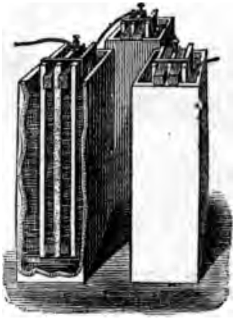
**Different Methods of producing the Voltaic Current.**—A voltaic current is always produced when two metals are placed in a conducting liquid, on one of which the chemical action of the liquid is more powerful than on the other. It is not necessary, therefore, that one of the metals should be positive and the other negative, but only that one of them should be more positive than the other, and the electro-motive force of the current is always in proportion to this difference between the two plates. In all ordinary arrangements for originating a voltaic-current oxygen is the negative element of the liquid, which is attracted to the most positive plate. If, therefore, one of the plates attract the oxygen more powerfully than the other, it will be impelled towards that plate with a force which is the difference between the two attractions, and the greater, therefore, this difference is, the greater is the force of the current.

Thus, if two plates of pure zinc or of pure platinum be inserted in a conducting liquid no current is set up, for the oxygen is as much attracted by one plate as the other. Almost all the early methods of originating a current consisted of two metals and one liquid; the vessel containing the liquid was called the cell, and a cell containing the liquid and the two metals formed a **galvanic** or **voltaic pair**. A number of these cells joined together formed a galvanic battery.

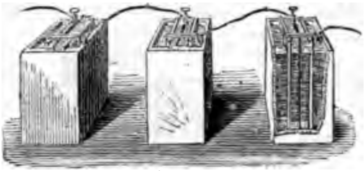
**Volta's Pile.**—This was the earliest form of the galvanic battery, and, as previously stated, was discovered by Volta in 1799. Very soon after an account of it reached England, and in 1800 Carlisle and Nicholson decomposed water with it. It consisted of a number of circular plates soldered together, so that all the copper plates faced in one direction, and the zinc ones in the other; and between each plate a wet cloth, moistened by salt and water or dilute sulphuric acid. These were kept in position by glass rods, the top and bottom plates being joined by a conducting wire, which conducted the positive current from the last copper to the first zinc; the current then passing up the piles from the zinc through the wet cloth to the copper. As this battery depended for its action on the moisture of the cloth, and the weight of the plates tended to squeeze out this moisture and stop the action, Volta, to prevent this, invented his **crown of cups**, in which the pieces of copper and zinc were soldered together in the form of an arc, and each end of these arcs placed in a cup or glass containing the exciting fluid. In 1802, Cruishank improved on this arrangement by placing the copper and zinc plates in one trough, into which he poured the dilute sulphuric acid, and this arrangement is still occasionally in use, though instead of using dilute sulphuric acid as the exciting liquid, sulphate of copper is used, which very much increases its action, and consequently the **electro-motive force.**

VOLTA'S BATTERY.

**Wollaston's Battery.**—In 1803, Wollaston, adopting the improvement of Cruishank, and knowing that as the zinc plate was the one gradually consumed away by the action of the acid, whilst the copper remained uninjured, used in his battery *thick* plates of zinc, which he surrounded by *thin* strips of copper, so that each side of the zinc plate should be equally exposed to chemical action, and thus the **electro-motive force** increased. This form of the battery is sometimes still used, but in all cases of one liquid and two metals, however powerful the action is at the commencement whilst the plates are clean, soon after the action commences there is a gradual decrease in the power of the cell, and it grows feebler and feebler the longer the action continues. This decrease of power, called polarisation of the plates, arises partly from the decrease in the strength of the acid, but chiefly from the hydrogen set free from the liquid accumulating on the negative plate, and thus tending to set up a current in the opposite direction. It has been previously stated that the real force of the current arises from the difference of the attraction of the two plates used for the oxygen, or other negative element of the fluid, and that the greater this difference the greater the force of the generated current. Now when any element has been just separated from any compound, it is much more powerful to form new combinations than at any other time, and is said to be in a *nascent* condition. The hydrogen then liberated on the negative plate is in this *nascent* state, and tends to unite itself again with the oxygen, from which it has just been separated by the zinc; and thus tends to draw the oxygen in an opposite direction and set up a contrary current. To prevent, therefore, this accumulation of hydrogen on the negative plate, and the consequent weakening of the strength of the current, was soon seen to be of the utmost importance, and for the first attempt at a remedy, whilst still retaining the ordinary arrangement of a single fluid and two metals, we are indebted to Mr. Smee.

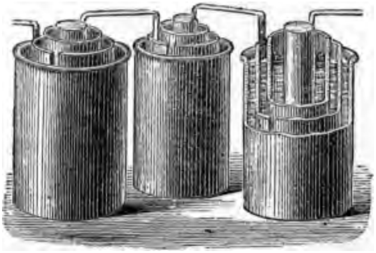

WOLLASTON'S BATTERY.

**Smee's Battery.**—This arrangement is something similar to Wollaston's, only that instead of copper he uses a fine plate of silver, surrounded by thick plates of zinc. It is found that hydrogen escapes from any surface more readily in proportion to its *irregularity*, and the number of points it offers for the hydrogen to escape. Smee, therefore, covered the silver plate with finely-divided platinum, the irregularity of the surface of which allows the hydrogen to escape more freely than from the even surface of any of the other metals. This battery is still frequently in use, especially by medical men, as from the simplicity of its structure, and its freedom from the escape of injurious gases, it is more suitable for a sick room; and from its greater constancy in action it is also superior to any other combination of one fluid and two metals.

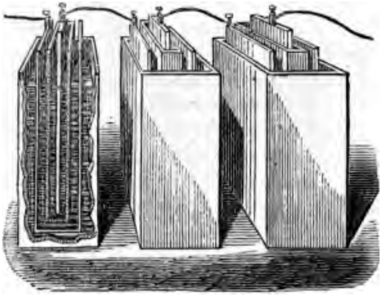

SMEE'S BATTERY.

**Batteries with two fluids.**—Although Mr. Smee's is an improvement on most of the single fluid batteries, yet it is neither powerful enough nor constant enough in its action, where either a *large quantity* or a *constant supply* of electricity is required. It is, therefore, of the utmost importance to find some means for getting rid of the hydrogen without allowing it to accumulate on the negative plate. Several attempts, both of a mechanical and a chemical nature, were resorted to by scientific men to effect this. One of the most important was to mix some other liquid with the dilute acid with which the hydrogen had a tendency to combine; and for this purpose nitric acid and sulphate of copper were added; the liberated hydrogen forming peroxide of nitrogen and water with the nitric acid, and taking the place of the copper in the sulphate of copper, so that pure copper, instead of hydrogen, is deposited on the plate. A disadvantage, however, arose from this mixture, as some of the copper was deposited on the zinc, as well as on the copper plate, causing a local action and an escape of hydrogen from different parts of the zinc plate.

**Daniell's Battery.**—Professor Daniell was the first to clearly enunciate these facts, and also to find out a remedy by separating the two liquids by a porous diaphragm. Originally this diaphragm was a piece of sailcloth or bladder, but now it, in nearly all cases, is formed of unglazed porcelain, which admits of the action of the current through it, and yet, mechanically, prevents any great mixture of the two fluids. In the interior of the porous vessel is placed a plate of amalgamated zinc, in a dilute solution of sulphuric acid, and this is placed in a copper vessel which is nearly filled with sulphate of copper. The hydrogen, then, on being liberated from the sulphuric acid, passes on its way to the copper through the porous diaphragm into the sulphate of copper, and forms sulphuric acid, pure copper being deposited on the copper plate. This is called, from the constancy of its action, **Daniell's constant battery**; and with suitable regulations it will remain in use for almost any length of time without its action being much impaired. On this account this, or some modification thereof, is used at a great number of the electric telegraph stations throughout the world; and no arrangement differing in principle from it is found nearly so useful where continuous and constant generation of electricity is required.


DANIELL'S BATTERY.

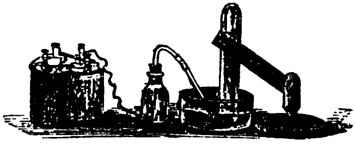
**Grove's Battery.**—Though Daniell's battery is the most constant in its action and less disagreeable in working than any of the constant batteries, it is not the most powerful, as there is not the same **electromotive force** originated between the zinc and copper as there is between zinc and carbon, or between zinc and platinum. This consists of a strip of platinum inserted in the porous vessel, which is then filled with strong nitric acid; the zinc being placed in an outer vessel along with dilute sulphuric acid. The action, therefore, commences in the outer cell, and the liberated hydrogen passes through the porous diaphragm and combines with part of the oxygen in the nitric acid. This battery, from the liquid being one of the best conductors, and from the plates employed differing most in their attraction for the negative oxygen, forms one of the most powerful combinations known. A heavy brown gas, peroxide of nitrogen, is, however, given off by the nitric acid, which is peculiarly irritating to the lungs and injurious to the health if breathed for any length of time or in great quantity. It is, therefore, important where this battery is used for any length of time that it should either be placed outside the room where experiments are performed, or the porous cell should be fitted with a plug to prevent the escape of the gas.



GROVE'S BATTERY.

**Bunsen's Battery** is in every respect similar to that of Grove's, only that **graphite** or **carbon** is used instead of platinum; and as this can generally be obtained from the retorts where gas is manufactured, it can be obtained much cheaper than platinum. Where economy, then, is an object, Bunsen's battery is preferable to Grove's; but in other respects their power is equal; and Grove's battery is neater and more compact.

**Instruments for detecting and measuring the Electric Currents.**—The Galvanometer.—It has been previously stated that if a freely-suspended magnetic needle be placed over a wire through which the current is passing it will be deflected from the magnetic meridian and make an angle with it, greater or less according to the size of the needle and the strength of the current. The amount, therefore, of the deflection of the needle *will be a* measure of the strength of the current. But many currents are too weak to overcome the action of the earth, and therefore what is termed the **multiplying galvanometer** is generally used. This consists of a coil of wire in the centre of which the needle is balanced, so that the current passes through the wire both *over* and *under* the needle. But as it passes *over* the needle in one direction and *under* it in another, its tendency is, in both cases, to deflect the needle in the same direction; and were it not for the increased resistance, owing to the length of the wire, its force to deflect the needle would be increased as many times as there were coils. When, however, it is requisite either **to detect the presence** or **measure the strength** of very weak currents, it is necessary to use a more delicate instrument, and for this purpose an **astatic galvanometer** is used. In using the others, to obtain anything like accurate results, it is always necessary to place the wire through which the current is passing in the magnetic meridian, for otherwise the action of the earth itself would cause the needle to make an angle with the wire. The astatic galvanometer consists of two needles of equal strength fixed together, with the north pole of one over the south pole of the other, so that the action of the earth is neutralised; for its tendency to turn, say, the north pole of one towards the north is balanced by its equal tendency to turn the south pole of the other towards the south. One of these needles is placed inside the coil of wire, and the other above it; and for detecting very feeble currents the coil consists of an immense number of turns of the wire, which is very fine, and carefully insulated by being bound round with silk.



THE VOLTAMETER.

**The Voltameter.**—This, as its name implies, is also a measurer of the strength of an electric current, and depends upon the amount of water it will decompose in a given time; as it is well known that this is always proportionate to the strength of the current.

Water, as previously stated, was first decomposed by Volta's pile in 1800; but Faraday was the inventor of the voltameter, which consists of two pieces of platinum soldered to the ends of wires, which, by binding screws, can be connected with the wires of a battery, the current strength of which is to be determined, These pieces of platinum are placed in a bottle containing acidulated water, and glass tubes are arranged to receive the gas given off by the decomposition of the water. These tubes are graduated so that the quantity of the gases given off in a given time can at once be seen, and this quantity is a measure of the strength of the current.

### QUESTIONS ON CHAPTER XXVI.

1. When will Voltaic currents always be produced?
2. What is a Voltaic cell? What forms a battery?
3. Describe Volta's pile and crown of cups: how did Cruishank improve it?
4. Describe Wollaston's battery, and how Smee's differs from it.
5. What are the defects of all single-fluid batteries, and what attempts had been made to overcome them?
6. Describe Daniell's battery, and its superiority to all previously used.
7. Describe Grove's and Bunsen's batteries, and how they differ from each other.
8. Describe the *galvanometer*, and explain its action.
9. Who invented the *voltameter*? and explain how it determines the strength of a voltaic current.

◆

## CHAPTER XXVII.

The Electric Telegraph: Historical Account of: its Different Parts and their Uses. Submarine Telegraphs. System of Signals: Wheatstone and Cooke's, Morse's, &c. The Indicator.

**The Electric Telegraph.**—One of the most important applications of voltaic electricity is that of conveying quickly messages to a distance; for though the word "telegraph" literally means, writing at a distance, it is used for any means of communication by signals, whether those signals are to be seen or heard. Perhaps the earliest means of conveying news of any sudden or expected danger was by lighting large fires on hills, which were called beacon fires; and many of our hills are still called beacons, in consequence of having been used for this purpose. It was by this means that England generally received the news of the advance of the Spanish Armada; and similarly it was expected that most parts of England would receive notice of the landing of Napoleon, had he invaded England. A system of signals, however, of a more complicated kind had long been in use at this latter period; and it was by means of such signals that Nelson gave the well-known message to his fleet ere the battle of Trafalgar. All these kinds of signals, however, could only be of use when they could be seen. A foggy day, the darkness of night, or intervening obstacles of any kind always prevented the possibility of these signals being seen, and consequently rendered them useless. In the electric telegraph, however, we have a means of rapid communication which can communicate its messages at any time, over any irregularity of district, and which can be communicated to distances where sight would be impossible. In the year 1820, Ampère suggested the possibility of communicating, by means of a galvanometer and a wire, with distant stations; but it was not till 1833 that any attempt was made to carry out the suggestion. The year 1837, however, is the most memorable in connection with the electric telegraph; as in that year three patents were obtained for its practical application. One was by Cooke and Wheatstone, in June, 1837, which was put in use on the Great Western Railway; and in the same year, Steinhill, of Munich, and Professor Morse, each brought their systems into operation over lines of greater or less length. The electric telegraph, whatever be its form, consists essentially of four parts, viz.:—

1st. A battery to originate the electro-motive force.
2nd. A conducting medium of communication with the station to which the messages are to be sent.

3rd. **A system of Signals,** which must be agreed upon and understood by the person sending and the one receiving the message.

4th. **An indicator,** to exhibit these signals at the distant station.

1st. The battery may be of any form, but some modification of Daniell's is now most commonly used in this country: where, however, great obstacles have to be overcome, and the lines are of great length, some modification of Grove's or Bunsen's batteries is frequently used.

2nd. The conducting medium between the stations is in all cases some kind of insulated wires, which used generally to be of copper, but which are now nearly always made of iron coated with zinc. Along nearly all our railway lines, except those of large towns, those wires are supported by posts and stretched over porcelain or glass, to insulate them. These posts are generally 18 to 20 feet high, and placed at distances of from 80 to 100 yards, according to the number of wires they have to carry. As voltaic electricity possesses such feeble tension, there is no tendency in the current to pass from the wire into the air; but where the wire comes into actual contact with any solid substance—as in passing over the posts—it requires to be well insulated, or a portion of the electricity will pass down these posts into the ground. This is especially the case in foggy or very wet weather, as the posts are liable to become more or less covered with moisture. In all the early telegraphs two wires were used to connect the stations so as to complete the circuit. In 1838, however, Steinhill, knowing that the current would pass through liquid, in the ordinary voltaic cell to complete the circuit, tried whether it would return in the same way for longer distances; and, finding that it would, he tried whether it would not equally return through moist earth, and ultimately had the satisfaction of knowing that if sufficiently large plates were buried in moist earth at each station, the circuit would thus be completed by the earth, no matter how distant the stations were from each other. Though the earth is, with regard to its materials, a much worse conductor than the metals, yet as the resistance decreases with the thickness, the earth may be considered as a wire so thick that its resistance need not be taken into account. To ensure the earth acting, instead of a second wire, however, the plates should not only be buried in moist earth, or connected with water-pipes, but should be of a sectional area not less than from 15 to 20 feet. In large towns and other places, where the wires cannot be well-supported by posts, they are frequently buried, like gas-pipes and water-pipes, in the ground. Several of these wires, well insulated by gutta-percha or caoutchouc, are placed together in tubes, and then a number of these tubes are enclosed in an iron pipe of sufficient thickness to resist the pressure upon them.

**Submarine Telegraphic Lines.**—These always consist of what is called a **cable**, and the wires are made of copper instead of galvanised iron, as it is desirable they should be as light as possible. The core or conducting part of the cable is made of one solid wire, or of a number of finer wires well insulated from each other by gutta-percha, caoutchouc, and other substances of an insulating nature that fill up the interstices between the wires and unite them into one solid substance. The core is now again surrounded by gutta-percha or caoutchouc, and frequently outside this by hemp coated with tar, and then, outside the whole, it is surrounded by iron sheathing to give the cable the necessary strength.

3rd. **System of Signals.**—The most important classes of signals depend upon either the power of the current to deflect a magnetic needle or to impart magnetic properties to soft iron. Depending on the *former* are all the **needle telegraphs**; whilst depending on the *latter* are the systems of Morse and Steinhill.

**Cooke and Wheatstone's Telegraph Needle** simply requires it to be determined beforehand how many turns to the right or left should stand for any particular letter; and as the movements of the needle are similar at the two stations, this requires to be understood by the person receiving the message, and he can at once write it down. Thus, as illustrations of this, in their first alphabet, one deflection to the right stood for **m**; two, for **n**; three, for **o**; four, for **p**; whilst two to the *left* stood for **a**; three, for **b**; four, for **c**, &c.

**Morse's system,** on the other hand, depends upon the power of the current to impart momentary magnetism to soft iron, which the moment the current ceases loses its magnetic power. It is only necessary, therefore, to place this piece of soft iron so near to a lever that it shall attract *downwards* one end when magnetic, and allow it to *rise* again when it lost its magnetism. If, when one end of the lever is thus pulled down, the other end is made to press, with a pencil or pen, against a piece of paper constantly kept moving by clockwork—according as the pen or pencil is pressed against this paper for a longer or shorter time—it will trace thereon a long or short line; and if it be made only to touch it momentarily, it will simply make a dot. In this system **the dots and lines stand for letters,** and these are marked upon the paper so that the message can be read and written out *after*, instead of *during* the time of its transmission. A good clerk, however, used to this method, does not require to see the paper, but can read the message as it comes, by simply listening to the taps of the pencil against the paper. Other signals, such as ringing bells of different tones, or partly muffled, are also in use; but the most common are those of Morse, or of Cooke and Wheatstone, though they are variously modified in practice by different companies by whom they are used.

4th. **The Indicator.**—In the needle telegraph this consists of an upright astatic galvanometer, with the needles loaded at the lower end to keep them in the upright position when not deflected by the current. In the single-needle telegraph one of the astatic needles is out of sight in the coil, and the other moves on the face of the dial and is the real indicator. In the double-needle telegraph there are two dials and two *pairs* of astatic needles. In Morse's system the paper on which the pencil presses, and even the taps of the pencil when writing, indicate the message to the receiver; and, as previously mentioned, sometimes different kinds of bells answer the same purpose.

### QUESTIONS ON CHAPTER XXVII.

1. What were the ancient systems of telegraphs, and in what were they all defective?
2. Who first suggested telegraphing by electricity?
3. When, where, and by whom was it first practically carried into effect?
4. What are the essential parts of an electric telegraph?
5. Describe the conducting medium generally used on land, and the way it is arranged.
6. Describe an electric cable.
7. Describe the needle telegraph.
8. Explain fully Morse's system, and mode of its action.

## CHAPTER XXVIII.

Electrolysis. An Electrolyte: what it must consist of. Atomic Weights. Electrolysis of Salt Water, Dilute Sulphuric Acid, Hydrochloric Acid, and Sulphate of Copper. Action of Daniell's, Bunsen's, and Grove's Batteries.

**Electrolysis** is the separation of compound bodies by the agency of electricity. It was previously stated that water was decomposed by Volta's pile in the year 1800. Soon afterwards Sir Humphry Davy, by means of the voltaic current, discovered **potassium, sodium, magnesium,** and various other metals, by separating them from their combinations with oxygen. Before this time **potass, soda,** and **magnesia** had been considered simple bodies, and incapable of further decomposition. The body decomposed by the battery is called the **electrolyte,** and it must be a **compound body,** as a simple elementary body is, of course, incapable of decomposition. It must also be **a fluid,** for, unless the molecules of the compound have freedom of motion amongst themselves, they are incapable of being separated. Solid bodies are, therefore, incapable of forming electrolytes till they are dissolved, and assume the liquid form, so that potass, soda, &c., must be dissolved in a liquid before they can be decomposed by the current into oxygen and the metals forming their base.

**Gaseous bodies** are also incapable of acting as **electrolytes**, or of being decomposed by the voltaic battery, on account of their incapacity to conduct the current. It is true that, in some cases, gases are decomposed to a small extent by electricity, as in the cases of the formation of **ozone**, and of small quantities of nitrogen, by the passage of electricity; but these cases are exceptional, and there is no mixture of gases that can be *definitely* separated by the current in the same way as fluids.

An **electrolyte** must also be composed of **a conductor** and a **non-conductor**; for a compound body composed of **two conductors**, or of **two non-conductors**, is incapable of decomposition by the voltaic current. It must also be composed of an **electro-positive** and an **electro-negative** element; the **electro-positive** being the **conductor**, and the **electro-negative** being the **non-conductor.** In **electrolysis**, then, the **electro-negative non-conducting** element of the electrolyte is always carried by the current in *one direction*, towards the positive plate; and the **electro-positive conducting** element in the opposite direction, towards the negative plate. The whole of the fluid between the two plates is thus **polarized**, all the **electro-negative** elements being turned towards the positive plate, and the whole of the **electro-positive** elements being turned towards the negative plate. The **electrolyte** must be also capable of conducting the current, or otherwise no electrolysis can take place; and the amount of decomposition by the current is always proportionate to the conducting power of the fluid in which the plates are placed. Thus water *alone*, which is a very bad conductor, is decomposed with great difficulty; but the addition of any acid or salt, which improves very greatly its conducting power, also increases proportionately the amount decomposed in a given time.

The decomposition of compound bodies by the electric current is always in definite proportions; these proportions being as the chemical equivalents of the liberated elements, but not necessarily in the proportion of their atomic weights. It has been previously stated that all compound bodies are made up of atoms supposed to be of the same size, but to differ in weight, and that the comparative weights of these atoms are called **atomic weights**, of which the weight of an atom of hydrogen is taken as the standard.

Now, if all atoms were not only of the same size, but had the same quantity of electricity connected with them, their **atomic weights** and their **chemical equivalents** would be the same, and the quantity of any element liberated by the current would be proportionate to the atomic weight. Take, for example, water, $OH_2$, the molecule of which is composed of one atom of oxygen and two of hydrogen. It is assumed that the one atom of oxygen contains as much negative electricity as the two atoms of hydrogen contain of positive; and that therefore, **electrically** and **chemically**, as one atom of oxygen is equivalent to two of hydrogen, so, in electrolysis of water, the weights of the gases given off are not as 16 to 1, but as **16** to **2**, or 8 to 1, though the atomic weight of oxygen, as compared with hydrogen, is 16 to 1.

The following are the atomic weights of some of the elements more commonly separated from their compounds by electrolysis:—

| | | | |
|---|---|---|---|
| Bromine . . . . | 80 | Nitrogen . . . . | 14 |
| Calcium . . . . | 40 | Oxygen . . . . | 16 |
| Chlorine . . . . | 35·5 | Potassium . . . . | 39 |
| Copper . . . . | 63·5 | Sodium . . . . | 23 |
| Hydrogen . . . | 1 | Sulphur . . . . | 32 |
| Iodine . . . . | 127 | Zinc . . . . . | 65 |

*Corresponding Chemical Equivalents.*

| | | | |
|---|---|---|---|
| Bromine . . . . | 80 | Nitric acid . . . | 54 |
| Calcium . . . . | 20 | Oxygen . . . . | 8 |
| Chlorine . . . . | 35·5 | Potassium . . . | 39 |
| Copper . . . . | 31·75 | Sodium . . . . | 23 |
| Hydrogen . . . | 1 | Sulphuric acid . . | 40 |
| Iodine . . . . | 127 | Zinc . . . . . | 32·5 |

The atomic weights of hydrogen, chlorine, bromine, iodine, fluorine, potassium, and sodium are the same as their chemical equivalents; whilst oxygen, zinc, copper, lead, &c., because each atom has double the amount of electricity connected with it, have their chemical equivalents only equal to half their atomic weights. Each atom will, therefore, when decomposed from a compound, liberate two atoms of these elements, whose chemical equivalents and atomic weights are the same.

Any **electrolyte** can originate an electric current, when two plates, whose attraction for oxygen differs, are placed in it and joined together outside the liquid. In all ordinary arrangements, however, water forms the chief part of the liquid, and is decomposed either as a primary or secondary action of the current. In the combinations with two metals and one liquid, the liquid is generally salt and water, dilute sulphuric or hydrochloric acids, or a solution of sulphate of copper. Electrolysis of each takes place as under:

1st. **Salt Water.**—When a zinc and platinum plate are immersed in a solution of salt, or chloride of sodium, it is decomposed, the chlorine combining with the zinc to form chloride of zinc, whilst the sodium is set free at the negative plate. The sodium, however, when liberated at the negative plate, immediately combines with the oxygen of the water, forming $Ha_2O$, or common soda, and setting the hydrogen free on the negative plate. At the same time the chloride of zinc, which is a highly deliquescent substance, is no sooner formed than it is again dissolved in the water, so that its saline character is but little affected by the process. The separation, then, of the chlorine and the sodium is owing to the direct action of the voltaic current, whilst the liberation of hydrogen on the negative plate is a *secondary* chemical action; and many persons believe that in *all cases* where water is decomposed, it is owing to *secondary* action, and that water *entirely* free from all acid or other impurities cannot be an electrolyte, or be decomposed by the voltaic current.

2nd. **Dilute Sulphuric Acid, $SO_4H_2$.**—In this case the oxygen and the sulphur are **electro-negative**, and the hydrogen **positive.** The action commences by the strong *attraction* of the zinc for the **sulphion, $SO_4$,** an atom of which combines with an atom of zinc, setting the hydrogen free. This hydrogen being in its **nascent state,** seizes, on its way to the negative plate, on the next atom of **sulphion,** forming sulphuric acid, and setting the hydrogen free, which again combines with another atom of sulphion to reform sulphuric acid in the following manner:—

*Arrangement before Commencement of Action.*

Plate. Plate.

$$\text{Zn}, \overline{\text{SO}_4\text{H}_2}, \overline{\text{SO}_4\text{H}_2}, \overline{\text{SO}_4\text{H}_2}, \overline{\text{SO}_4\text{H}_2}, \text{Cu}.$$

*Arrangement after Commencement of Action.*

$$\overline{\text{ZnSO}_4}, \overline{\text{H}_2\text{SO}_4}, \overline{\text{H}_2\text{SO}_4}, \overline{\text{H}_2\text{SO}_4}, \overline{\text{H}_2\text{SO}_4}, \overline{\text{H}_2\text{Cu}}.$$

Hence sulphate of zinc is continually being formed, and consequently the zinc plate constantly **losing weight,** whilst the hydrogen is set free constantly at the negative plate. This hydrogen being in its **nascent** state, and peculiarly active in its tendency to combination, has a strong tendency to *recombine* with the sulphion, and thus to set up a current in the opposite direction. The more hydrogen is accumulated on the negative plate, the greater is this tendency, and the more it weakens the original current. In this arrangement, for every 65 milligrammes of **pure zinc** which is lost by the positive plate, $\overset{\text{Zn}}{65} + \overset{\text{O}_4}{64} + \overset{\text{S}}{32} = 161$ milligrammes of sulphate of zinc are formed in the liquid, and 2 milligrammes of hydrogen gas are set free on the negative plate. If the ends of the wires connected with the zinc and copper plates terminated in platinum electrodes immersed in acidulated water, for every 65 milligrammes of zinc decomposed from the zinc plate, and consequent formation of 161 milligrammes of sulphate of zinc, 18 milligrammes of water would be decomposed in the vessel containing the platinum electrode; 16 of oxygen gas being set free at the platinum electrode connected with the copper, and 2 of hydrogen from that connected with the zinc plate.

3rd. **Hydrochloric Acid.**—If this acid, instead of sulphuric, be used as the exciting fluid, the following will represent the conditions before and after commencement of the action :—

*Arrangement before Commencement of Action.*

Plate. Plate.

$$\mathrm{Zn}, \overline{\mathrm{Cl_2H_2}}, \overline{\mathrm{Cl_2H_2}}, \overline{\mathrm{Cl_2H_2}}, \overline{\mathrm{Cl_2H_2}}, \mathrm{Cu}.$$

*After Commencement of Action.*

$$\mathrm{Zn}, \overline{\mathrm{Cl_2}}, \overline{\mathrm{H_2Cl_2}}, \overline{\mathrm{H_2Cl_2}}, \overline{\mathrm{H_2Cl_2}}, \overline{\mathrm{H_2Cl_2}}, \overline{\mathrm{H_2Cu}}.$$

In this case the negative chlorine would combine with the zinc; but as it would take **two atoms** of chlorine to be chemically equivalent to **one of zinc,** for every 65 milligrammes of zinc decomposed at the zinc plate, 2 × 35·5, or 71 milligrammes of chlorine, would be withdrawn from the acid, forming 65 + 71, or 136 milligrammes of **chloride of zinc**; whilst, as in the former case, 2 milligrammes of hydrogen would be set free on the negative plate.

4th. **Sulphate of Copper.**—If a solution of sulphate of copper be used as the exciting liquid, the sulphion combines with the zinc, and pure copper is deposited on the negative plate; but as this can only be used in connection with an acid, it is found much better to use it as an element of a compound battery than to use it in one containing only one liquid.

## COMPOUND BATTERIES OF TWO LIQUIDS AND TWO METALS.

It will only be necessary here to explain briefly the action of Daniell's, and Grove's or Bunsen's batteries.

**Daniell's Constant Battery.**—Here the action commences with the attraction of the **zinc for the sulphion,** and sulphate of zinc is formed, as in the preceding cases, *inside* the porous diaphragm, the hydrogen in its nascent state passing through the diaphragm, and seizing upon the sulphion of the sulphate of copper, and setting free the pure copper on the negative plate. The following will show the arrangement *before* and after the commencement of the action :—

*Before Commencement.*

$$\overset{\overset{+}{\text{Plate.}}}{\text{Zn},}\ \ \overline{SO_4H_2},\ \overline{SO_4H_2}\ \ \text{Diaphragm.}\ \ \overline{SO_4Cu},\ \overline{SO_4Cu},\ \overset{\overset{-}{\text{Plate.}}}{\text{Cu.}}$$

*Arrangement after Commencement of Action.*

$$\overline{ZnSO_4},\ \overline{H_2SO_4}\ \ \text{Diaphragm.}\ \ \overline{H_2SO_4},\ \overline{H_2SO_4},\ \ \overline{CuCu}.$$

There is, therefore, a constant formation of sulphate of zinc inside the diaphragm, and consequent weakening of the acid; whilst outside the diaphragm there is a constant formation of sulphuric acid, and a weakening of the solution of copper. To remedy this inconvenience, crystals of copper are placed in a bag outside the diaphragm, which dissolve quickly enough to keep up the strength of the solution of copper; whilst arrangements are made for drawing off the sulphate of zinc from the lower part of the vessel inside the diaphragm, and adding dilute acid to the upper part. For every 65 milligrammes of zinc decomposed from the zinc plate, there is formed, as before, 161 milligrammes of sulphate of zinc, and there is also deposited 63·5 milligrammes of copper on the negative plate.

**Bunsen's and Grove's Batteries.**—In these the action commences also in the affinity of the zinc for the sulphion of the sulphuric acid, the hydrogen set free passing through the diaphragm to the nitric acid, and there combining with the oxygen to form water, and setting free the peroxide of nitrogen, which escapes in fumes into the room.

The following will illustrate the arrangement before and after the commencement of the action :—

*Before Commencement.*

$$\overset{\text{Plate.}}{\text{Zn},}\ \ \overline{SO_4H_2},\ \overline{SO_4H_2}\ \ \text{Diaphragm.}\ \ \overline{N_2O_6H_2},\ \overline{N_2O_6H_2},\ \overset{\text{Plate.}}{\text{Pt.}}$$

*After Commencement of Action.*

$$\overline{ZnSO_4},\ H_2SO_4 \quad \text{Diaphragm} \quad \overline{H_4O_2},\ \overline{N_2O_6H_2},\ \overline{N_2O_4},\ Pt.$$

### QUESTIONS ON CHAPTER XXVIII.

1. What is *electrolysis*?
2. Of what must an electrolyte consist?
3. Explain what is meant by saying that the decomposition of compound bodies is always in definite proportions.
4. What substances have their *chemical equivalents* and *atomic weights* the same?
5. Under what circumstances can an electrolyte always originate a voltaic current?
6. Explain the electrolysis of salt water.
7. Explain the chemical action in a cell excited by dilute sulphuric acid.
8. What is being constantly formed at the positive plate, and how much weight will the zinc plate lose if two milligrammes of hydrogen are set free on the negative plate?
9. Describe the action in Daniell's constant battery.
10. What is the use of the diaphragm in batteries of two fluids?

## CHAPTER XXIX.

Electro-Metallurgy: Electrotyping, Electro-plating, Electro-gilding, Electro-zincing. Explosion of Gunpowder, Blasting, &c., by means of the Voltaic Current.

**Electro-Metallurgy.**—The next important use of the electric current is for **electrotyping, electro-gilding,** &c.

**Electrotyping.**—Very soon after Daniell had discovered, and brought into use his constant battery, he noticed that the copper deposited on the negative plate, if the force of the battery was not too great, was deposited as a continuous sheet, on the inner surface of which all the irregularities of the negative plate were faithfully and exactly reproduced. Professor Daniell, however, made no real use of this discovery; and it was not till the year 1839 that Professor Jacobi, of *St. Petersburg,* announced his discovery that, by means of the voltaic current, he could obtain exact copies of any metallic surface. Very soon after this, Spencer and Jordan, who had each independently arrived at the same practical result, published the methods they adopted; and further improvements were soon made by Mr. Elkington, in England, and by M. Ruolz, in France. They, however, used the process more for **electro-plating** than for **electrotyping**. It is obvious that impressions made by any object on the coating of copper laid upon it by the voltaic current will be exactly opposite to those upon the object itself, all the parts in relief producing depressions in the copper coating, whilst all the depressions of the object will be in relief. To obtain, then, a copy corresponding to the original object it is necessary to use the first impression as an original object, and then the inner surface of the copper deposited upon this copy will exactly correspond to the original object. To avoid the delay and inconvenience of this method, a cast of the object is generally made first. This cast may be made of any fusible metal, of gutta-percha, stearin, or wax. If, however, the object to be copied be a **non-conductor** of electricity, it is necessary to coat the part to be copied with some conducting substance, or otherwise the copper will not be deposited on its surface. Plumbago is generally used for this purpose, as a thin layer of it can be easily and cheaply applied, and it also prevents the too firm adherence of the copper to the object, and thus allows them to be easily separated when the copy has been obtained.

To illustrate the general method of procedure, we will suppose that a medal is to be copied by this process. A cast of the medal is first obtained by means of any substance which expands on solidifying, so as to make a sharp and clear impression. Suppose the cast to be of **gutta-percha**, into which a wire is inserted so that it may be suspended by it in the bath. As gutta-percha is not a conductor, the side containing the negative impression is brushed over by a fine camel-hair pencil with plumbago, to make its surface conducting. It is then suspended in a bath of sulphate of copper, from a rod which is connected with the zinc plate of a Daniell's battery, and a piece of copper about the same size as the medal is suspended by another wire from a rod connected with the copper plate of the same battery, the solution of the sulphate of copper completing the circuit between the two rods. If the battery be not too powerful, the cast will be coated evenly with a fine sheet of metallic copper, which will be an exact *fac-simile* of the original medal; whilst the piece of copper suspended from the other wire will gradually lose as much weight of copper as is deposited upon the cast, so that the strength of the bath will remain constant. It will then only be necessary to separate carefully the coating of copper from the cast, which in all ordinary cases is done without the least difficulty, the coating of plumbago, or even the oxide of the metal itself, when a cast is not used, preventing the coating of copper from adhering too firmly for the separation to be easily effected.

Electrotyping is of great use in the arts, and many large and valuable copper-plates engraved for the Art Union have been electrotyped with success; and by its means engravings on copper of all descriptions are largely multiplied. Engravings on wood can also be converted into copper by this means, and rare and valuable bronzes can also in this way be copied. So faithfully and minutely accurate are copies obtained by this means, that copies of daguerreotype plates have been thus obtained which faithfully represent the original in the most minute particulars.

**Electro-plating.**—In electro-plating, electro-gilding, electro-zincing, &c., there is this great difference from electrotyping—that whilst in the latter it is always necessary to remove the impression obtained from the original, in the former the coating of gold, silver, or zinc is intended to be firmly adherent to the surface on which it is placed. Great care is therefore necessary in cleansing the surface of the body to be plated or gilt from all substances which would prevent perfect adhesion between the coating and the body. For this *purpose* the bodies to be plated—which are generally of **brass**, **bronze**, **copper**, or **German silver**—are first *heated* strongly, to remove from them any fatty matters which have adhered to them, and this heating is generally effected by boiling them in a solution of caustic potash. After this they are, whilst still hot, placed in dilute nitric acid, to remove any film of oxide which has been formed upon them by the action of the atmosphere. They are then scoured with fine sand, and afterwards either dipped in strong nitric acid, or washed with nitrate of mercury, which last process leaves on them a thin film of mercury which acts as a cement between the article and the coating of silver, and makes it adhere more firmly. The articles to be plated are placed in a bath containing generally **cyanide of silver**, dissolved in **cyanide of potassium**. A solution which contains about one-fiftieth of its weight of silver generally answers well in practice, and articles well plated should be coated with from an ounce to an ounce and a-half of silver to the square foot, the coating then being about the thickness of ordinary writing-paper. Articles made of iron, zinc, Britannia-metal, lead, or tin, cannot be **electro-plated** properly, because the silver will not adhere with sufficient firmness to these substances; but if they be first coated with **copper**, then they may afterwards be electro-plated, as the copper will adhere firmly to these metals, and then the silver will adhere with equal firmness to the copper with which they are coated. When bodies are electro-plated they have a dull chalky appearance, and require to be burnished before they assume the brilliant lustre of polished silver. Recently, however, it has been discovered that by adding a small quantity of **carbonic bisulphide** to the bath, the silver deposited acquires at once the lustre of the burnished metal. Great care, however, is necessary when the bisulphide is thus used; so that many persons prefer to dispense with it, and to give the lustre required by burnishing after the electro-plating has been effected.

**Electro-gilding.**—This process differs very little, except in the bath used, from **electro-plating**, and nearly all the metals, when properly cleansed, can be covered successfully with a coating of gold. The bath consists generally of **cyanide of gold** dissolved in **cyanide of potassium**, and the solution generally contains about one part in a hundred of gold, or about half the quantity of silver used for electro-plating. The old method of gilding was by using an amalgam of gold and mercury, but this method was very injurious to the persons employed, owing to the fumes of mercury disengaged during the process, and this method is now entirely superseded by that of the voltaic current. Gilding with gold-leaf is, however, still used for many purposes such as picture frames, and gilding letters in printing, or on banners, sign-boards, &c. Gold may be made to adhere to almost any other metal by the voltaic process, but is fixed the most firmly on silver; and it is on this account that the wires of ear-rings, and other parts of jewellery, where it is important that a thin coating of gold should adhere with great firmness, are usually made of silver.

**Electro-zincing.**—This is now extensively carried on in order that the metal thus coated with zinc may be protected from the corroding action of the weather and prevented from combining with oxygen, or rusting. Zinc is the most positive metal in ordinary use, and if it be connected with any other metal *less positive than itself*, it entirely protects the less positive metal from corrosive action; just as a lightning-conductor protects a building, because the lightning passes along it in preference to passing by any worse conductor than itself. If ordinary iron, for instance, be placed in **hydrochloric** acid, the iron will be attacked and eaten away by the acid; but if the piece of iron be in contact with zinc, no effect will be produced by the acid upon the iron so long as any zinc remains thus connected with it. Sir Humphry Davy thus discovered that the copper bottoms of ships might thus be protected from the action of sea-water, by being partly coated with zinc. This discovery, however valuable in itself, was useless for the purpose intended, as the copper thus protected ceased to be injurious to animal or vegetable life; and *the consequence* was, that shell-fish of all kinds adhered in such numbers to the bottoms of the vessels as to impede their passage through the water. The great value of this discovery, however, arises from its use in coating iron, which is thus made almost as valuable in resisting the action of the weather as platinum or other more valuable metals. Iron thus coated is, from the process used, said to be **galvanized**; and galvanized iron is now extensively used for boilers, flues of stoves, wires for **telegraphic** and other purposes, and also for lightning-conductors.

**Explosion of Gunpowder by the Voltaic Current.**—The best conductors of electricity are **gold, silver,** and **copper,** whilst amongt the worst conductors of the metals are **iron, tin, platinum,** and **lead.** But the metals all conduct electricity better in proportion to their thickness; so that a thick wire of any kind will conduct a voltaic current much more readily than a thin one. But the greater resistance a wire of any kind offers to the progress of the current, the greater is its temperature increased by its passage. Thus, if the voltaic current be made to pass through a chain composed of any kind of metal, some links of which are made of **very fine,** and others of **very thick** wire, the very thin links may be rendered hot, whilst the thick ones have their temperature but slightly raised. If, also, a chain, the links of which are all equally thick, have them made alternately of copper and platinum, those of platinum will be made quite hot, whilst those of copper will remain comparatively cool. If, then, a chain be made of alternate links of platinum and copper, and the copper links are made of thick, whilst those of platinum are made of thin wire, on sending a voltaic current through the chain the links of platinum may be made of a **white heat,** whilst the temperature of the thick copper links is but very slightly increased. It is evident, therefore, that if it be desired to explode gunpowder by voltaic agency, it is only necessary to make a circuit of **thick copper wire** connected by a **thin wire of iron or platinum,** and to let this thin wire pass through the gunpowder. The passage of the current will then raise the temperature of the platinum, or iron wire, sufficiently high to ignite the gunpowder and cause an explosion to take place. Since the year 1838, when Mr. Roberts devised this method, it has been nearly always employed for blasting rocks and firing mines of all descriptions. It is also by modifications of the same method that torpedoes and mines are caused to explode in time of war; and though in coal-mines the old methods of blasting are still very generally adopted, yet, in blasting of rocks on a large scale, the safer and more certain plan of firing the gunpowder by means of the voltaic current is nearly always used.

### QUESTIONS ON CHAPTER XXIX.

1. Explain the origin of electrotyping.
2. Who first discovered it? and who brought the discovery into actual use?
3. Explain the method adopted in copying a medal by this process.
4. Of what use is electrotyping in the arts?
5. What is the difference between *electro-plating* and *electrotyping*?
6. What bodies are generally electro-plated?
7. What was the old method of gilding?
8. What metal can be best gilt?
9. What important purpose is effected by coating copper, iron, &c., by zinc?
10. What metals are the best, and which the worst conductors of electricity?
11. What effect has *thickness* on the conducting power of metallic wire?
12. Explain the best method of exploding powder in blasting rocks, exploding mines, &c.

THE END.

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